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14. ABSTRACT
Situation awareness (SA) is the psychological ability and capacity to perceive information and act on it acceptably. This ability is central to human behavior. Existing theoretical models explain many aspects of SA; however, knowledge about its development out of basic perceptual abilities was insufficient. This quantitative research examined basic neurocognitive factors in order to identify their specific contributions to the formation of SA, to address this fundamental discontinuity in theory. Piloting was the chosen task. Visual attentiveness (Va), perceptiveness (Vp), and spatial working memory (Vswm) were assessed as predictors of SA under varying task difficulty. Factorial and repeated-measures ANOVAs, Pearson correlation, and linear multiple regression modeling were used to determine the effects of these independent variables on the dependent variable SA and the interactions. The study participants were 19 C-27J pilots, selected from the Ohio Air National Guard. Neurocognitive tests were administered to the participants prior to flight. In-flight SA was objectively and subjectively assessed for 24 flights. At the completion of this field experiment, the data were analyzed and the tests were statistically significant for the three predictor visual abilities Vp, Va, and Vswm as task difficulty was varied, $F(3,11) = 8.125$, $p = .008$. In addition, multiple regression analyses revealed that the visual abilities together predicted a majority of the variance in SA, R2 = 0.753, $p = .008$. Moreover, the Pearson correlation results indicated that Vp ($r[12] = -0.816$, $p = .002$) had the strongest relationship of the three neurocognitive factors for the overall flight. Post-hoc tests revealed a Cohen's yielding statistical power to be 0.98. This indicates that possessing the ability to have a perceptivity, to be insightful, and to have discernment, is most important. During high task difficulty Va ($r[12] = -0.583$, $p = .046$) had the strongest correlation with SA, while during low task difficulty it was Vswm ($r[12] = -0.634$, $p = .026$). This work results in a significant contribution to the field by providing an improved understanding of SA, an *Enhanced-Theoretical Model of SA*, and potentially safer travel for society worldwide. It is recommended research be extended to other populations.

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A Neuroergonomic Quasi-Experiment: Predictors of Situation Awareness and Display Usability with USAF Pilots while Performing Complex Tasks

Dissertation

Submitted to Northcentral University

Graduate Faculty of the School of Behavioral Health Sciences
in Partial Fulfillment of the
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DOCTOR OF PHILOSOPHY

by

STEVEN D. HARBOUR

Prescott Valley, Arizona
February 2015

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A Neuroergonomic Quasi-Experiment: Predictors of Situation Awareness and Display Usability with USAF Pilots while Performing Complex Tasks

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Abstract

Situation awareness (SA) is the psychological ability and capacity to perceive information and act on it acceptably. This ability is central to human behavior. Existing theoretical models explain many aspects of SA; however, knowledge about its development out of basic perceptual abilities was insufficient. This quantitative research examined basic neurocognitive factors in order to identify their specific contributions to the formation of SA, to address this fundamental discontinuity in theory. Piloting was the chosen task. Visual attentiveness (V_a), perceptiveness (V_p), and spatial working memory (V_{swm}) were assessed as predictors of SA under varying task difficulty. Factorial and repeated-measures ANOVAs, Pearson correlation, and linear multiple regression modeling were used to determine the effects of these independent variables on the dependent variable SA and the interactions. The study participants were 19 C-27J pilots, selected from the Ohio Air National Guard. Neurocognitive tests were administered to the participants prior to flight. In-flight SA was objectively and subjectively assessed for 24 flights. At the completion of this field experiment, the data were analyzed and the tests were statistically significant for the three predictor visual abilities V_p, V_a, and V_{swm} as task difficulty was varied, $F(3,11) = 8.125$, $p = .008$. In addition, multiple regression analyses revealed that the visual abilities together predicted a majority of the variance in SA, $R^2 = 0.753$, $p = .008$. Moreover, the Pearson correlation results indicated that V_p ($r[12] = -0.816$, $p = .002$) had the strongest relationship of the three neurocognitive factors for the overall flight. Post-hoc tests revealed a Cohen's $f^2 = 3.05$ yielding statistical power to be 0.98. This indicates that possessing the ability to have a perceptivity, to be insightful, and to have discernment, is most important. During high task difficulty V_a (r[12] = -0.583, p = .046) had the strongest correlation with SA, while during low task difficulty it was V_{swm} (r[12] = -0.634, p = .026). This work results in a significant contribution to the field by providing an improved understanding of SA, an *Enhanced-Theoretical Model of SA*, and potentially safer travel for society worldwide. It is recommended research be extended to other populations.

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First, I would like to dedicate this dissertation in loving memory of my parents, Major General **<Deleted>**, USAF retired and **<Deleted>**, who passed away in 2008, one year after I started this journey. They bestowed within me character, family, duty, and service, a quest for scientific knowledge and a tenacious drive to succeed. Furthermore, I would like to recognize my late father-in-law **<Deleted>** whose ancestry signed the Declaration of Independence and my late mother-in-law **<Deleted>**. They always gave me words of encouragement and Carroll's favorite acrobatic phrase "the dreaded spin" always brought a smile to my face when I needed it most. Utmost importantly, I would like to especially thank my loving and supportive wife, **<Deleted>** and children, **<Deleted>** and **<Deleted>**, for their support, help, and understanding for those countless hours and days that I spent studying, researching, investigating, interning, teaching, experimenting, and writing, for the past 8 years; they truly have made this Ph.D. a reality.

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Chapter 1: Introduction

Cognitive situation awareness has been a topic of research in the behavioral sciences for some time. Situation awareness may be simply defined as the human ability to perceive and comprehend the environment, and use that information to accomplish a task (Endsley, 1995a). Previous exploration had suggested that cognitive situation awareness is critical to a broad range of human performance, but most notably in aviation (Bailey, Shelton, & Arthur, 2011; Cass, 2011; Crawford & Neal, 2006; Salmon, et al., 2010; Kim, 2009; Wickens, 2008). In aviation from 1980 to 2007, 983 accidents occurred worldwide involving aircraft without an installed Head Up Display (HUD) (Flight Safety Foundation, 2009). A recent review of this accident data revealed that the majority were due to reduced cognitive situation awareness and increased mental workload of the aviator, combined with limited visibility, and operations into austere locations (Arthur, Prinzel, Williams, & Kramer, 2006; Bulkley, Dyre, Lew, & Caufield, 2009; Flight Safety Foundation, 2009; NTSB, 2009). Despite the importance of situation awareness in human performance, there was no consensus on predictors or antecedents (it was unpredictable), an area that tended to be elusive and theoretically vague (Cass, 2011; Douglas, Aleva, & Havig, 2007; Dekker & Hollnagel, 2004; Gorman, Cooke, & Winner, 2006; Harbour, Hudson, & Zehner, 2012; Jodlowski, 2008; Rousseau, Tremblay, & Breton, 2004; Sulistyawati, Wickens, & Chui, 2011; Wickens, 2002, 2008). A better understanding of the antecedents of situation awareness will advance the theory of how situation awareness is formed and maintained, as well as produce improvements that could apply to any task involving visual displays and information integration.

The focus of this project was to conduct neuroergonomic empirical studies that would identify the basic abilities that are essential antecedents of situation awareness (causing it to be predictable). As the scientific concept of situation awareness must be defined with respect to a particular task, this project focused on the complex multitask of piloting a USAF aircraft. To reduce the confounds of variance in pilot populations and aircraft types, the scope was confined to the USAF Air National Guard population who fly tactical airlift in north central Ohio with emphasis on task saturating phases of flight, where situation awareness was especially stressed due to increased mental workload (FSF, 2009). It should enhance behavioral science in this area by shedding light on the significance of visual attention and visuospatial working memory as the antecedents or predictors of cognitive situation awareness. In doing so, this work will answer the literature's exigent call to advance cognitive situation awareness theory (Endsley, 2012; Gutzwiller & Clegg, 2012; Harbour & Hudson, 2012; Sulistyawati, Wickens, & Chui, 2011; Vidulich & Tsang, 2012; Wickens & McCarley, 2008), while addressing a problem of real-world significance (Bulkley, Dyre, Lew, & Caufield, 2009; Flight Safety Foundation, 2009; NTSB, 2009; Wickens & McCarley, 2008).

Background

The goal of this research was to address a discontinuity in situation awareness theory that needed to be linked by examining pilot neurocognitive factors as predictors of situation awareness (SA). Previous exploration suggested that SA is vital to pilot performance and preventing accidents (Bailey, Shelton, & Arthur, 2011; Cass, 2011; Crawford & Neal, 2006; Salmon, et al., 2010; Kim, 2009; Wickens, 2008); however, there was no consensus on predictors for SA, an area that tended to be mysterious (Cass, 2011; Douglas, Aleva, & Havig, 2007; Dekker & Hollnagel, 2004; Gorman, Cooke, & Winner, 2006; Harbour, Hudson, & Zehner, 2012; Jodlowski, 2008; Rousseau, Tremblay, & Breton, 2004; Sulistyawati, Wickens, & Chui, 2011; Wickens, 2002, 2008).

This neuroergonomic study reports results obtained from USAF pilots performing routine training missions (non-simulated). Cognitive and visual abilities were measured and tested as predictors of SA, which were assessed by both post flight subjective self-report and in flight objectively measured changes in heart rate, heart rate variability, and brainwave activity. Cognitive and visual ability were tested via the Integrated Visual and Auditory performance plus (IVA+) test, which incorporates measurements of response time, mental processing speed, working memory, divided attention, response inhibition, comprehension, accuracy, and vigilance (Brain Train, 2010; Corbett & Constantine, 2007; Tinius, 2003; Turner & Sandford, 1995). Specifically, visual abilities were associated with changes in SA and pilot mental workload in memory-intensive flight environments, as a function of phase of flight and display used (Parasuraman, Sheridan, & Wickens, 2008; Parasuraman & Wilson, 2008). As will be discussed next, different cockpit displays or display designs promote or impair SA, producing meaningful variation against which to correlate visual ability. The results add to and modify the Theoretical Model of Situation Awareness, wherein ability (in this case visual) is predictive of greater SA.

Neuroergonomics is an emerging, interdisciplinary area of research whose purpose is to enhance knowledge of brain activity, function, and human behavior as encountered at work and in natural settings (Parasuraman, Christensen, & Grafton, 2012). It is integrated research between psychology, cognitive neuroscience, human factors, engineering, computer science, ergonomics, and medicine (Lees, Cosman, Lee, Fricke, & Rizzo, 2010). For example, neuroergonomics can focus on the psychology of perceptual and cognitive functions and actions in relation to actual technologies (Parasuraman et al., 2012). A premise of this multidisciplinary approach is that knowledge in the psychological sciences will be enhanced. *Neuroergonomics: The Brain at Work* (Parasuraman and Rizzo, 2008) indicated this composite exploration is growing and is being fueled by the emergence of information-saturated information display (ID) technology that is now being used by humans for activities requiring divided attention and multitasking (Parasuraman, Christensen, & Grafton, 2012). Neuroergonomics provides a novel approach as a contemporary perspective in science, with human situation awareness (SA) research as an integral part (Lees, et al., 2010; Parasuraman et al., 2012; Parasuraman & Rizzo, 2008; Parasuraman, Sheridan, & Wickens, 2008; Parasuraman & Wilson, 2008; Wilson, Estepp, & Davis, 2009). This work adopted a neuroergonomic approach, as will be discussed in detail later.

In the literature, SA is often discussed using philosophical concepts (Blandford & Wong, 2004; Dekker & Hollnagel, 2004; Elliott et al., 2009; Gorman, Cooke, & Winner 2006; Jodlowski, 2008; Nullmeyer, Herz, & Montijo, 2009; Rousseau, Tremblay, & Breton, 2004; Shelton, et. al, 2009). Situation Awareness (SA) is currently viewed as a complicated tangible that exists and necessitates a keen sense for visual cues (Billingsley, Kuchar, & Jacobson, 2001; Endsley, 2012; Parasuraman, Sheridan, & Wickens, 2008). As a starting point, SA could be described as the cognitive awareness level by the pilot as it relates to aircraft flight (Tsang & Vidulich, 2003, 2006; Vidulich & Tsang, 2012). Bringing into consciousness the characteristics that develop during tasks in order to project into the future is SA (Endsley, 1995a, 1995b; Wickens, 1992). At the fundamental level of SA, the pilot needs to accurately perceive relevant information (Endsley, 1995a, 1995b). Endsley's (2012) Theoretical Model of SA (TMSA) submits there are a total of three levels for SA: a) perception (Level 1), b) comprehension (Level 2), and c) projection (Level 3).

The concept of Mental Workload (WL) is the level of demand imposed by tasks on the pilot's limited mental resources (Wickens & Hollands, 2000). It is related to both demand and cognitive capacity (Wickens, 2008). The demand is imposed by mental tasks on the human, whether considered as single or multiple (Wickens, 2008). WL in aviation is environment driven; therefore, it is driven by the stimulus and activity involved, and it is not something that is necessarily self-paced. Abstractly, WL can reflect a subjective experience of mental effort (Dekker & Hollnagel, 2004). In straightforward and simple terms, WL is the level of mental effort a given individual has when performing tasks such as aviating, which consume cognitive capacity. In summary, WL is a function of both task difficulty and individual capability (J.C. Christensen, personal communication, Jan 10, 2012). As one measures the current psychological and physiological state of an individual, one is measuring mental workload and in turn, cognitive situation awareness (Gutzwiller & Clegg, 2012).

Neuroergonomic methods provide a framework for this field study integrating subjective and objective measures using a multidisciplinary approach to studying the brain at work in the cockpit measuring possible SA predictors. Adopting neuroergonomic methods, psychophysiological assessment of the effects of varying task difficulty (based on display design) in actual flight with neurocognitive factors as independent variables has substantial potential for improving our understanding of SA and WL, and the relationship between the two (Bailey, et al 2011; Campbell, 2010; Campbell, Castaneda, & Pulos, 2010; Crawford & Neal, 2006; Douglas, Aleva, & Havig, 2007; Flight Safety Foundation, 2009; Geiselman & Havig, 2011; Harbour, Christensen, Estepp, & Gray, 2012; Harbour, Hudson, & Zehner, 2012; Kim, 2009; Kramer et al., 2005; Wickens, 2008; Wickens, Levinthal, & Rice, 2010). This study was focused on SA and WL, with display design used as a commonly encountered factor that can affect WL and SA; it was performed in the actual aircraft as the test bed utilizing qualified pilots as subjects.

Deficient situation awareness can lead to fatal accidents, in particular the number-one killer in commercial aviation, controlled flight into terrain (CFIT, Wickens & McCarley, 2008). It has been reported that if situation awareness could be improved this accident potential could be reduced from 33 to 73 percent, saving lives and an estimated $1 million per commercial and military aircraft over the next 10 years (FSF, 2009; Prinzel & Risser, 2004; Rockwell Collins, 2000). This affects society worldwide. This dissertation was virtuous in inquiry and discovery, uncovering and determining the scientific need and solution.

Statement of the Problem

The problem addressed was that despite the scientific exigency, there were no precise predictive components of current theories of situation awareness and associated specific quantifiable cognitive and perceptual processes (Douglas, Aleva, & Havig, 2007; Ellis & Levy, 2009; Elliott et al., 2009; Endsley, 2012; Gillan et al., 2009; Gugerty, in press; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Lau, Jamieson, & Skranning, 2013; Proctor & Vu, 2010; Sulistyawati, Wickens, & Chui, 2011; Vidulich & Tsang, 2012; Wickens, 2008; Wickens & McCarley, 2008; Tirre & Gugerty, 1999, 2000). In the face of nearly two decades of work since Endsley's Theoretical Model of Situation Awareness (TMSA, 1995a) was first published, models of situation awareness were still conceptual models that provided little specificity with regards to the neurocognitive processes that are necessary for the formation and maintenance of situation awareness (Gillan et al., 2009; Lau, Jamieson, & Skranning, 2013; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). While the TMSA recognizes perception as a critical first step, there were no specific or quantitative links between perceptual abilities and situation awareness; nor has subsequent work been able to clarify the issue, e.g. the effects of visual ability on the level of situation awareness (Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Vidulich & Tsang, 2012; Sulistyawati, Wickens, & Chui, 2011). Needed theoretical advancement in this area continued to be hampered by a lack of specific, testable predictions regarding plausible component processes; there had been little theoretical progress due to this (Douglas, Aleva, & Havig, 2007; Endsley, 2012; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens, 2008; Sulistyawati, Wickens, & Chui, 2011).

The seminal research done by Tirre and Gugerty (1999, 2000), Wickens and McCarley (2008), Elliott et al., (2009), Jen-li, et al., (2013), and Gugerty, (in press) found that visual processing (Proctor & Vu, 2010), was involved in situation awareness (Vidulich & Tsang, 2012). However, the specific component processes had not been explored in detail (Gutzwiller & Clegg, 2012; Gugerty, in press; Harbour et al., 2012;

Jen-li et al., 2013; Jones & Endsley, 2012; Sulistyawati et al., 2011; Vidulich & Tsang, 2012). The current study therefore tested explicit hypotheses regarding specific abilities that may contribute to situation awareness; the results fill in a critical gap in the TMSA, and in so doing enable both theoretical refinement (providing an *Enhanced-Theoretical Model of SA*) and practical applications such as improved procedures, training for pilots, and display design that improve flight safety (Endsley, 2012; FSF, 2009; Prinzel & Risser, 2004; Rockwell Collins, 2000; Vidulich & Tsang, 2012; Wickens & McCarley, 2008).

Purpose of the Study

Visual processing can be categorized as static and dynamic (Proctor & Vu, 2010), and may be operationalized as visual attentiveness and perceptiveness, integrated with visuospatial memory (Brain Train, 2010; Christensen et al., 2013; Corbett & Constantine, 2007; Endsley, 2012; Gugerty, in press; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). Consequently, the primary purpose of this quasi-experimental quantitative study was to test the predictive value of these specific candidate visuo-cognitive abilities: (a) Visual Attentiveness, consisting of Vigilance, Focus, and Speed (b) Visual Perceptiveness, consisting of Prudence, Consistency, and Stamina, and (c) Visuospatial Working Memory, consisting of working memory that is stored in the visuospatial sketchpad of the mind as predictors of situation awareness, e.g. the effects of visual ability on the level of situation awareness. Therefore, this project tested the predictive value of these variables as factors between a particular task to be performed and the eventual outcome of situation awareness. As Pavlov, Watson, and Skinner conducted field experiments in order to contribute to psychological theory (Cervone & Pervin, 2007), a field experiment in the paradigm of neuroergonomics (Parasuraman, Christensen, & Grafton, 2012) employing quasi-experimental repeated-measures (within-participants), was utilized for this study.

This was the most effective and realistic method to perform the research that addressed the problem and the purpose. As computed by *a priori* power analysis, this study required a sample size of a minimum of 12 United States Air Force (USAF) pilots. These pilots were recruited at an airport in north central Ohio by utilizing a recruitment memo and posters in squadron buildings. All participants were pilots qualified in the aircraft. Two display conditions varied the difficulty of maintaining SA by changing the presence and position of the flight information display. The first condition had an Information Display (ID) design that was near optimal and centered on the pilot's field of view and was no more than five degrees above or below the pilot's line of sight (Harbour, Hudson, & Zehner, 2012). The second condition had an ID design that was suboptimal and well out of pilot line-of-sight (a 35-degree vertical drop) (Harbour et al., 2012) see Figure 3. This display manipulation induced variation in task difficulty, with differential effects on both subjective and psychophysiological measures (Capó-Aponte et al., 2009; Proctor & Vu, 2010). This work was successful, and will result in significant elaboration of theoretical models of situation awareness as well as enabling and focusing efforts to improve situation awareness.

Theoretical Framework

The identified theoretical foundations for this study are based primarily in the Theoretical Model of Situation Awareness (TMSA) as described by Endsley (1995a). There are at least three different theories for situation awareness (Stanton, Chambers, &

Piggott, 2001), the *TMSA* – a three level model that uses a cognitive/information processing approach (Endsley, 1995a), the *theory of activity model* that describes situation awareness (Bedny & Meister, 1999), and the *perceptual cycle theory model* that is an ecological approach (Niesser, 1976; Smith & Hancock, 1995). These theories diverge in their foundational psychological construction (Salmon et al., 2008). The *theory of activity model* varies from the TMSA in that it describes situation awareness using eight functional blocks and posits that the degree to which blocks are engaged is contingent upon the character of the task and the individual's goals (Stanton et al., 2001). The *perceptual cycle theory model* is an alternative view of situation awareness, in that it is not dependent on the domain or the individual, rather it is a function amidst the interaction of the domain with the individual (Stanton et al., 2001). This study focused on the TMSA, as it is by far the most widely accepted model of situation awareness (Endsley, 2012; Vidulich & Tsang, 2012).

Endsley's framework is grounded in hierarchical levels of cognitive situation awareness and is based on information processing. In this *theory as narrative,* Level 1 situation awareness contains the perception and processing of cues (Endsley, 2012; Wickens, 2008; Wickens et al., 2008). The TMSA simply states that Level 1 situation awareness is achieved when cues are perceived. It makes no particular claims about which perceptual abilities are critical to this process or how individual differences may contribute to the relative ease of achieving Level 1. Level 2 situation awareness is the comprehension of the current situation by utilizing the information gained from Level 1 (Endsley, 2000a, 1995a; Wickens, 2008). Level 3 situation awareness is the utilization of the situation model to project and predict the future state (Endsley, 1995a, 2000b;

Sulistyawati, Wickens, & Chui, 2011; Wickens, 2009). Endsley's (1995a, 2002a) view of situation awareness is becoming utilized more and more as the basis for research in areas such as system displays (Capó-Aponte et al., 2009; Eid, Johnsen, & Brun, 2004).

The seminal research done by Tirre and Gugerty (1999, 2000), Wickens and McCarley (2008), Elliott et al., (2009), Jen-li, et al., (2013), and Gugerty, (in press) found that visual processing (Proctor & Vu, 2010), was involved in situation awareness (Vidulich & Tsang, 2012). However, the specific component processes had not been explored in detail (Gutzwiller & Clegg, 2012; Gugerty, in press; Harbour et al., 2012; Jen-li et al., 2013; Jones & Endsley, 2012; Sulistyawati et al., 2011; Vidulich & Tsang, 2012). This work, therefore, tested explicit hypotheses regarding specific abilities that contribute to situation awareness; the results of this study fill in this crucial gap in the TMSA.

Visual processing can be categorized as static and dynamic (Proctor & Vu, 2010), and may be operationalized as visual attentiveness and perceptiveness, integrated with visuospatial memory (Brain Train, 2010; Christensen et al., 2013; Corbett & Constantine, 2007; Endsley, 2012; Gugerty, in press; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). Accordingly, the primary objective of this quasi-experimental quantitative study was to test the predictive value of these specific candidate visuo-cognitive abilities, Visual Attentiveness, Visual Perceptiveness, and Visuospatial Working Memory, as predictors of situation awareness. Therefore, this project tested the predictive value of these variables as factors between a particular task to be performed and the eventual outcome of situation awareness.

Sixteen quantitative experiments and fifteen research articles have illustrated the need and attempted to discover the detailed links between vision, cognition, predictability, and situation awareness. Over this 15-year period, up to and including current present day, the research has gotten closer, illustrating the continuing need to fill this gap in the TMSA. Additionally, three other theories and or models have links to the TMSA and they are Applied Attention Theory (AAT) (Wickens & McCarley, 2008), Multiple Resource Theory (MRT) (Sarter, 2012), and the Salience Effort Expectancy Value (SEEV) Model (Wickens & McCarley, 2008). Five quantitative experiments and six research articles have shown these to be linked and influenced by the TMSA; consequently, this research could benefit those theories as well. This dissertation identified critical variables underlying the formation of situation awareness as well as the relationships among these variables filling this scientific void in theory (Elliott et al, 2009), grounding the TMSA in specific and quantifiable perception and cognitive processes.

What is known is that situation awareness plays a vital role in dynamic decision-making environments (St. John & Smallman, 2008). However, further controversy existed regarding specific details of TMSA. Endsley's theory emphasizes perception and comprehension of the environment amid projection into the future; however, it does not contain enough granularity or accuracy in the area of human perception (Elliott et. al., 2009; Gorman et al., 2006; Jodlowski, 2008; Stanton et al., 2001; Wickens, 2008). The TMSA does not emphasize reflective relationships between mental models and knowledge of the present system.

Based on multiple regression analyses, dynamic visual processing, visual search, time-sharing, and temporal processing were the attributes that made significant unique contributions under the TMSA framework, however the exact knowledge of how, in what way, and or why they affected situation awareness was unknown (Tirre & Gugerty, 1999, 2000). In this seminal work the other two discovered attributes; static visual processing and working memory, were corollary but with " mixed evidence," (Tirre & Gugerty, 1999, p. 18). The working memory (WM) and SA relationship results as part of the multivariate analysis were inconclusive with little to no correlation, but do play a role in some way, as well. That work did not clarify which basic visual processing elements, such as visual attentiveness and visual perceptiveness (as characteristics of dynamic visual processing) are significant predictors of SA.

Tirre and Gugerty (1999, 2000) indicated that even though this research opened the door to examining candidate cognitive factors for situation awareness, the understanding of visual processing factors operating in a dynamic environment was incomplete, and hoped that improved understanding of the role played by these abilities in forming and maintain situation awareness would be achieved in future research.

Wickens (2008) clearly showed that pilots who failed to detect an unexpected event lacked complete Level 1 situation awareness; consequently, display design and attentional tunneling are influences on situation awareness. However, the degree to which improved visual attention prevents attentional tunneling, hence improving situation awareness, was unknown. Applied Attention Theory (AAT) (Wickens & McCarley, 2008) indicates that visual attention control, scanning, information sampling, visual search, spatial attention and displays play a role in pilot mental workload, which in turn would imply an influence on situation awareness as well. Wickens (2008) discovered that visual search and attention were unique factors for workload. However, an understanding of visual processing factors operating in dynamic environments related to attention was incomplete (Wickens & McCarley, 2008, p. 38). This too is linked to the TMSA.

This recent finding by Elliot et al. (2009) reemphasized that vision is the most dominant sense when it comes to influencing situation awareness (Wade & Swanston, 2012), consequently focusing research on elucidating the visual attributes for situation awareness will have the greatest impact. Elliot et al. (2009) provided additional knowledge to build upon when researching visual cuing, displays, and the neurocognitive factors involved in Level 1 situation awareness prediction. This study identified areas in need of further investigation, specifically work on relating factors and refining guiding principles to determine when, why, and how cues come into play to support human performance in demanding or complex environments. Studies need to further investigate and refine theory-driven predictions for workload and demands for attentional abilities to include visual cuing (Elliot et al., 2009; Strater, Riley, Faulkner, Hyatt, & Endsley, 2006).

Endsley's view of situation awareness - the TMSA - is often utilized as the basis for research in areas such as system displays and military operations (Sulistyawati, Wickens, & Chui, 2011). Level 3 situation awareness is the utilization of the situation model to project and predict the future state (Sulistyawati, Wickens, & Chui, 2011). What was needed in future research was to specifically investigate neurocognitive characteristics such as visual attention and visual-spatial working memory, and the effects on pilot workload and situation awareness (Sulistyawati, Wickens, & Chui, 2011). There was a lack and need for additional psychological theory that is based on the neurocognitive abilities to perceive the visual display's cues, predicting situation awareness and workload that is Level 1 situation awareness (Sulistyawati, Wickens, & Chui, 2011). Research continued to struggle to find detailed links between the cognitive demands on pilots and situation awareness.

The research performed by Jen-li, Ruey-Yun, and Ching-Jung (2013) examined display design for unmanned aerial vehicle (UAV) monitoring, and its effects on operator situation awareness, performance, and mental workload involving the TMSA. The operator in UAV flights has to rely primarily on vision in this agent-based system, consequently the question remained what role does display design and human visual abilities play in the human-robot interface in order to enhance situation awareness (Jones, Connors, & Endsley, 2011).

The results illustrated that compared to the conventional display, the effects of a situation-augmented display on flight completion time and abnormality detection time were robust across different workloads but error rate and perceived mental workload were unaffected by the display type. With the increasing complexity of new automation technology, there is a significant challenge to researchers to better understand the underlying cognitive and visual processes in order to aid the control operator's situation awareness. An important point gained from this study is that the Level 1 SA from the TMSA still presented problems for these researchers in that they had difficulty in assessing the interaction between operator visual abilities and display usability (Jen-li et al., 2013). More studies were needed to address these unresolved and important issues (Jen-li et al., 2013) expanding the TMSA.

The very recent in-press work by Gugerty investigated and discussed probable component processes, both perceptual and cognitive, that support situation awareness during real-time tasks. The psychological field needs a better understanding for the foundation of theoretical models, so that through empirical evidence a better conception between situation awareness and its component processes can be achieved (Gugerty, in press). Situation awareness is a complex process that requires further assessment (Gugerty, in press).

Gugerty posited that the cognitive process for Level 1 SA could potentially be automatic, and therefore would place almost no demands on cognitive resources; however, this does not explain the cognitive demands of attention and vigilance, which are known to be demanding and stressful (Warm, Parasuraman, & Matthews, 2008). Gugerty contested that the TMSA three-level view of SA processes is at odds when it comes to maintaining SA versus acquiring SA. Future research needs to narrow or broaden this view (Gugerty, in press).

The work of Gugerty indicated that increasing SA knowledge further, needs to be accomplished by discovering, measuring, and quantitatively explaining, describing, and linking these specific key perceptual factors (visual abilities), with the goal being to objectively fill the foundational gaps solidly grounding the TMSA. The following relates the TMSA with AAT, MRT, and the SEEV Model. Wickens and McCarley's (2008) Applied Attention Theory (AAT), offers further support for this research in that AAT indicates that visual attention control, scanning, information sampling, visual search, spatial attention and displays play a role in pilot mental workload, which in turn would imply an influence on situation awareness as well, linking it to the TMSA. Additionally, further AAT clearly illustrates that an understanding of visual processing factors operating in dynamic environments related to attention was incomplete, providing further evidence of the necessity of this dissertation study (Wickens & McCarley, 2008). Moreover, Multiple Resource Theory (MRT) (Bulkley et. al, 2009; Lei & Roetting, 2011; Pickel & Staller, 2012; Sarter, 2012; Vidulich & Tsang, 2012) and the Salience Effort Expectancy Value (SEEV) model, which is linked to MRT through the visual modality, articulates the theoretical foundations of this study.

MRT is evolving and feeding application models as tools in improving interface design (Sarter, 2012). As discussed by Lei and Roetting (2011), Wickens has made advancements to MRT both in 2002 and again in 2008. These advancements have expanded MRT while adding detail and granularity. Current MRT submits that there are limitations to attention resources as before. Among other changes, current evidence supports that two aspects of visual processing, referred to as peripheral and focal (foveal) vision, appear to sometimes draw on separate resources, therefore tasks that draw on both aspects may result in relatively improved performance, while simultaneous tasks that load on only one aspect are likely to degrade performance when these processes occur simultaneously (Sarter, 2012), and these have potential direct links to the TMSA. Specifically, Level 1 SA should be enhanced by distributing information across multiple sensory modalities as well as between focal and peripheral vision; conversely, SA should be impaired by overloading one particular input modality. An important characteristic of this view of MRT is the proposal that the effect of task demand and resources may not be just qualitative but may also involve quantitative relationships (Embrey et al., 2006; Lei & Roetting, 2011; Padgett, 2004; Sarter, 2012; Vidulich & Tsang, 2012).

A theoretical model of selective attention called the Salience Effort Expectancy Value (SEEV) model links basic research psychological models such as the TMSA, salience and attention capture, engineering models, and expected value optimization (Wickens & McCarley, 2008). An example of SEEV's purpose could be to improve ID design in order to counteract inattention (Ma & Kaber, 2007; Matthews, Bryant, & Webb, 2001).

The SEEV is linked to MRT primarily through visual modality and it utilizes MRT in the creation of an attention based applications tool. More specifically, the SEEV uses foveal vision as attention directly from the MRT and potentially the TMSA. The parameters of the SEEV (Wickens & McCarley, 2008), which drive the visual attention around the environment, are: (1) Salience (S), the exogenous attention capturing properties of events, e.g. bright symbols that are salient on the ID, (2) Effort (Ef) that inhibits the movement of attention across longer distances, (3) Expectancy (Ex), the probability of seeing an event at a particular location, an endogenous cognitive factor that is calibrated by the individual to the frequency of events that occur at that location, and (4) Value (V), which is the importance (value) of tasks provided by the attended event, in addition to the relevance of the event to a valued task.

With the application of the SEEV model, aircraft cockpits could be designed such that the location and appearance of symbology on the display more effectively corresponds with the actual environment in the most efficient prioritized manner. What the SEEV model lacks is the influence of individual ability on visual attention (individual as “Liveware”; Edwards, 1972), i.e. the levels of the individual’s abilities in visual attentiveness, visual perceptiveness, and visual spatial working memory. Further individualization of SEEV would advance the theory by elucidating the effects of individual differences in visual abilities on resultant visual attention, which could conceivably result in individually customizable information displays that maximize usability.

There was a lack and need for additional psychological theory that is based on the neurocognitive abilities to perceive the visual display’s cues, predicting situation awareness and workload (Harbour, et. al., 2012; Kim, 2009; Endsley, 2012; Sulistyawati, et. al., 2011; Vidulich & Tsang, 2012) succinctly quantitatively grounding the TMSA. This is covered and expanded upon further in the Literature Review. This Ph.D. study makes a solid contribution to the literature in behavioral science by addressing a gap in cognitive situation awareness theory by way of examining both pilot neurocognitive factors and flight display three-dimensional placement, and how and why they affect situation awareness and workload.

Prior research is incomplete with regards to the exact role of visual processing abilities; future research needed to refine measurement of these abilities and was accomplished. Seminal work performed by Crawford and Neal (2006), and Gorman, Cooke, and Winner (2006) indicated the need for additional research examining the impact of HUD usage on situation awareness in flight, in particular, with respect to the prediction of situation awareness. The critical variables underlying the formation of situation awareness as well as the possible relationships among these variables needed to be identified. One assumption of the TMSA is that visual and cognitive factors influence situation awareness (Endsley, 1995a, 2012; Vidulich & Tsang, 2012). Previous research has indicated that complex tasks or difficulties in operation (visual factors and task difficulty) results in decreased situation awareness (FAA, 2011; Flight Safety Foundation, 2009; Kang, 2008; Kang, Yuan, Liu , & Liu, 2008; NTSB, 2009; Wickens, 2008). In this dissertation study, the visual factors are called “visual abilities” and vary as a function of the different individuals in the naturally occurring sample. In addition, a cognitive factor was called “task difficulty,” which was manipulated by the location of the display. According to the TMSA, it could be postulated that increased visual difficulty and or an increase in mental workload will decrease the level of situation awareness, however, the effects of visual ability on the level of situation awareness needed to be discovered, and were by this study.

Research Questions

This quantitative research utilized a quasi-experimental design that made use of repeated measures comparisons, with situation awareness as the dependent variable. The within-subjects and factors repeated-measures ANOVA was used along with the (Pearson) correlation, and linear multiple regression modeling in order to measure and determine the effects of the variables (independent / dependent), their interactions and importance, and the strength of association between variables. Each subject in the experiment was exposed to all levels and conditions. As mental workload goes up, cognitive situation awareness goes down (Gutzwiller & Clegg, 2012; Kokar & Endsley, 2012), consequently, as one measures the current psychological and physiological state of an individual, one is measuring mental workload and in turn, cognitive situation awareness (Gutzwiller & Clegg, 2012). Previous work has not, however, explored visual abilities as predictors of situation awareness with factors between task difficulty and situation awareness. The following research questions were explored to address the overarching question of identifying predictors of situation awareness under varying task difficulty.

In all three below questions, the visual abilities were evaluated as predictors (factors) of situation awareness. Task difficulty, in and of itself, was analyzed as a necessary manipulation check to verify that the conditions produced significant main effects on situation awareness; however this is not a central research question. A main effect of visual ability was probed with post hoc tests to determine which abilities contributed to an observed variation in situation awareness, likewise any interaction between visual abilities and task difficulty was assessed via post hoc tests. The bottom line is what are the effects of visual ability on the level of situation awareness? A detailed investigation that focused on the following main research questions was performed:

Q1. Under varying task difficulty, are there statistically significant effects of subject inherent visual attentiveness on situation awareness?

Q2. Under varying task difficulty, are there statistically significant effects of subject inherent visual perceptiveness on situation awareness?

Q3. Under varying task difficulty, are there statistically significant effects of subject inherent visual spatial working memory on situation awareness?

Hypothesis

To address the research questions, the following hypotheses were tested:

$H1_0$. Under varying task difficulty, there will be no statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

$H1_a$. Under varying task difficulty, there will be statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

$H2_0$. Under varying task difficulty, there will be no statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

$H2_a$. Under varying task difficulty, there will be statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

$H3_0$. Under varying task difficulty, there will be no statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

$H3_a$. Under varying task difficulty, there will be statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

Nature of the Study

This quasi-experimental quantitative study was to test the predictive value of these specific, candidate visuo-cognitive abilities (visual attentiveness and visual perceptiveness, and/or inherent visuo-spatial working memory) with respect to situation awareness (see Table 5). Therefore, this project tested the predictive value of these variables as factors between a particular task to be performed and the eventual outcome of situation awareness. Additionally, this quantitative study attempted to determine whether using a HUD or the HDD in the Cohen's Statistical Power Analysis (Cohen, 1992) sample minimum of 12 pilots, would improve or worsen situation awareness or workload, and interact with inherent visual abilities. This study utilized a within-subjects design with repeated measures on the two different display conditions for each one of the subjects. The sample was from the Ohio Air National Guard (ANG) pilot population, which is relatively homogeneous.

This quantitative research employed the ANOVA, along with multiple regression analysis and the Pearson correlation. The independent variables are the inherent visual abilities, and the dependent variable is a composite level of situation awareness. Task difficulty (HUD and HDD) was varied across each flight and was a controlled covariate variable.

Significance of the Study

This dissertation reviewed, studied, and or critically analyzed more than 300 references in its construction and bore 3-years to complete. Without research that makes the scientific links between basic visuo-cognitive abilities and situation awareness, there can be little progress in situation awareness theory. Current models of situation awareness were still conceptual models that provided low specificity with regards to the neurocognitive processes that are necessary for the formation and maintenance of situation awareness (Vidulich & Tsang, 2012; Wickens & McCarley, 2008).

This study supports theoretical advancement in this area by providing evidence regarding plausible component processes (Douglas, Aleva, & Havig, 2007; Endsley, 2012; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens, 2008; Sulistyawati, Wickens, & Chui, 2011). This work tested explicit hypotheses regarding these specific abilities that may or may not contribute to situation awareness. This effort was successful, and it will result in the problem that was addressed being solved; the scientific exigency was treated with precise and predictive metrics for current theories of situation awareness. The results enhance Endsley's Theoretical Model of Situation Awareness (TMSA, 1995a) by providing specificity concerning the neurocognitive processes that are necessary for the formation and maintenance of situation awareness. This study produced needed theoretical advancement in this area with results regarding plausible component processes; generating theoretical progress.

This study tested explicit hypotheses regarding specific abilities that may contribute to situation awareness; the results of this study fill in a critical gap in the TMSA, and in so doing enable both theoretical refinement and practical applications such as improved procedures, training for pilots, and display design that improve flight safety. It will result in significant elaboration of theoretical models of situation awareness as well as enabling and focusing efforts to improve situation awareness in many tasks and applications. Deficient situation awareness can lead to fatal accidents, in particular the number-one killer in commercial aviation, controlled flight into terrain (CFIT, Wickens & McCarley, 2008). This work is wholly successful, and results in both a significant addition to the existing TMSA and the basis for developing techniques to better select and train pilots, and design displays reducing the incidence of fatal aviation accidents.

Definition of Key Terms

Attention. It is the act of mentally concentrating on a task or tasks (Matlin, 2008).

Attentiveness. It consists of Vigilance, Focus, and Speed, and is applicable in both the static and dynamic environment, involving both static and dyamic visual processing (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Awareness. It is the ability to accurately perceive, from both the human senses and perception in the cockpit about flight, present, past, and future (Matlin, 2008). In real-world terms for aviation, it is the cognitive awareness level by the pilot as it relates to aircraft flight (Tsang & Vidulich, 2006).

Binocular instantaneous field of view (IFOV). It is the FOV visible to the eyes, the left and right at the same time (Newman, 1995).

Bore-sight. It is the information display system's alignment with respect to the reference axis of the aircraft (Newman, 1995).

Cockpit Design Eye Point (CDEP). This is the spatial location and pilot position in the cockpit where the pilot should sit in order to properly operate the aircraft (Harbour, Hudson, & Zehner, 2011; Newman, 1995). This position allows for optimal visibility both inside and outside, the pilot will have optimal aircraft controllability and cockpit reach, and proper visibility to take-off, fly, and land the aircraft safely. This position is a three dimensional point in space that will accommodate the pilot population extracted at the mid-pupil.

Cognition. It is the human process that is mental activity, which utilizes thoughts for acquiring, processing, storing, transforming, and using knowledge (Matlin, 2008).

Cognitive Situation Awareness. See Situation Awareness.

Combiner. It is the reflective sub-system component (semitransparent element / glass / lens) that is placed in the pilot's forward FOV that provides and has superimposed symbology on the external/outside FOV of the outside environment by utilizing collimation (Newman, 1995). It provides collimation by reflecting the light from the projector placing the light rays in parallel and does not spread out the light, as it propagates the short distance to the pilot's eyes (Wood & Howells, 2001). It is designed to project the image source information at optical infinity. The combiner has special coatings that combined with the lens simultaneously reflect the HUD information and transmit back, enabling the pilot to view both the outside world and the collimated display (Wood & Howells, 2001).

Consistency. It is the ability to stay on task, respond reliably, making dependable responses in a dynamic environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Divided attention. This is a higher cognitive process using working memory to perform two tasks near simultaneously, or while performing two cognitively diverse tasks near simultaneously (Wickens & McCarley, 2008).

Dynamic Environment. This is a non-static or changing environment that requires continual responses from the human operator. The human operator is in a state of dis-inhibition when working in this environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Dynamic Vision. It is visual processing that occurs in the non-static or changing environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Exit pupil (EP). It is a three dimensional disk in space that contains all of the light collected by the optics for the entire FOV (Newman, 1995). The maximum FOV is obtained at EP. The virtual aperture in an optical system is the EP.

Eye relief. It is the distance from EP to the HUD combiner surface (Newman, 1995)

Flight performance. It is how effectively the pilot aviates, navigates, and communicates in flight, in this order (Causse et al., 2011; Taylor, Bauer, Poland, & Windell, 2010).

Field of view (FOV). It is the spatial angle within which items are visible, that is degrees of visual angle relative to the size of visual stimuli. Specific to the HUD, this the angle within which the symbology may be viewed, it is measured laterally and vertically (Newman, 1995). For the purpose of this study, it is a binocular overlapping FOV and is where the two solid angles subtended at each eye by the clear apertures of the HUD optics intersection from a fixed head position within the HEMB (Harbour, Hudson, and Zehner, 2011).

Focus. It is the consistency (lack of variance) in reaction time speed to a change in the static and dynamic environment and reflects the sustaining and maintaining of attention (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Head down display (HDD). It is an electronic device that displays information on a screen to the pilot while looking down, however the pilot cannot see the actual outside environment through this type of display (Bailey, Shelton, & Arthur III, 2011)

Head up display (HUD). It is a cockpit display that provides primary flight information (PFI) to the pilot as he or she looks through the windscreen (Bailey et al., 2011; Newman, 1995). The symbology is presented as a virtual image focused at optical infinity.

Helmet mounted display (HMD). This is a display mounted on the pilot's helmet that performs the same operation as the HUD (Bailey, Shelton, & Arthur III, 2011; Newman, 2005).

HUD Eye Motion Box (HEMB). It is a three-dimensional envelope within which the pilot's eyes (measured at mid-pupil) need to be in order to accurately see 100% of the flight symbology (Harbour, Hudson, & Zehner, 2011).

Information Display (ID). It is a display to position or expand for view, with the use of an electronic unit, a visual representation of information in the form of a Head Up Display (HUD), a Helmet Mounted Display (HMD), a Head Worn Display (HWD), or a Head Down Display (HDD) (Bailey, Shelton, & Arthur III, 2011; Merriam-Webster, 2012; Newman, 1995). Consequently, it is comprised of what the right eye sees plus what the left eye sees from a fixed head position within the HEMB.

Line-of-Sight (LOS). It is, as the pilot sits in Cockpit Design Eye Point (CDEP), a line subtending from the pilot's mid-pupil horizontal to the aircraft's waterline centered along the aircraft's boresight.

Memory. It is the storage of information, either short-term (working memory) or long-term (Matlin, 2008; Klatzky, 1980).

Mental workload (WL). It is related to both demand and cognitive capacity (Wickens, 2008). The demand is imposed by tasks on the human's limited mental resources, whether considered as single or multiple (Wickens, 2008). However, more specifically mental workload for this study is an assessment of what proportion of mental capacity is demanded by a task. Mental workload can be measured as an implicit measurement of situation awareness (Gutzwiller & Clegg, 2012; Kokar & Endsley, 2012; Svensson & Wilson, 2002; Wilson & Russell, 2003; Wilson, et. al, 2009).

Neuroergonomics. It is integrated research between psychology, cognitive neuroscience, human factors, engineering, computer science, ergonomics, and medicine (Lees et al., 2010). The purpose is to enhance knowledge of brain activity, function, and human behavior as encountered at work and in natural settings (Parasuraman, Christensen, & Grafton, 2012).

Perception. It involves unaware inference utilizing both biological and psychological processes (Blake & Sekuler, 2006; Carlson, 2004). Items and or events in the environment give off clues to their existence, and the sensory organs detect these clues. Vision is one of the five senses and the most involved when interfacing with a HUD (Wickens, 2008). The raw beginnings of perception begin with visual sensation, first a stimulus occurs (Blake & Sekuler, 2006; Carlson, 2004). The human typically first mentally performs visual bottom-up processing then a fraction of a second later visual top-down processing.

Perceptiveness. It consists of Prudence, Consistency, and Stamina and is applicable in both the static and dynamic environment, involving both static and dyamic visual processing (Brain Train, 2010; Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Pilot. This refers to the operator of an aerospace vehicle either manned or unmanned (USAF, 2007).

Piloting. It is the act of controlling an aerospace vehicle. Piloting involves perception of flight-relevant information, attention, cognitive processing, memory, and motor responses to effect flight control.

Primary flight information (PFI). It is flight symbology that consist of representing aircraft: attitude (pitch and bank), heading, altitude, airspeed, and vertical velocity (in some cases, this also includes angle of attack, turn and slip, flight path marker, and g-meter indications) (USAF, 2007).

Prudence. It is the selection or choice of a correct response or responses in a dynamic and static environment (non-inhibited and inhibited). That is being non-impulsive, the ability to not automatically react yielding an incorrect response in the changing environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994)

Psychological Refractory Period (PRP). The fundamental idea of the PRP is that a second stimulus can be noticed while the first stimuli is still being processed, however later processes such as response selection for the second stimuli cannot begin until that for the first stimuli is completed (Proctor & Vu, 2010). In this study, this refers to the degree to which the stimuli needed to fly the airplane come from two different locations (e.g., FOV and LOS), each of which requires a cross check by the pilot. If they are in different locations they will be viewed by the pilot within a short time interval of a few hundred milliseconds or less, causing the response to the second stimulus to be delayed (Proctor & Vu, 2010; Vidulich & Tsang, 2012), thereby increasing task dificulty.

Reaction time. This is the time to respond to an incoming stimulus, measured from the moment that it is first perceptible to the moment a response is made is this time (McGrew, 2009).

Six degrees of freedom. It is the attitude of the aircraft (pitch, yaw, and roll) and the location of the aircraft (altitude, heading, and spatial position [latitude and longitude]) (Wickens, 2002).

Situation awareness (SA). Situation awareness is the psychological ability and capacity to perceive information and act on it acceptably. In real-world terms for aviation, it is the cognitive awareness level by the pilot as it relates to aircraft flight (Tsang & Vidulich, 2006). Aircraft flight can be described by six degrees of freedom; therefore an aspect of situation awareness is the cognitive awareness level by the pilot of those six degrees (Wickens, 2002). Those six degrees also move as a function of time, therefore situation awareness also includes time and change awareness. Situation awareness involves cognition and working memory, rather than action and response (Wickens, 2002). It feeds on the perception of the elements in one's world within a volume of space and time (Endsley, 2006).

Speed. It is defined as the average reaction time to changes in the environment. Speed measures discriminatory mental processing speed.

Speed-working memory (SWM). This is the reaction time-frame that includes the processes of memory, visual scanning, and perception. The speed of responses are measured in milliseconds to stimuli for cognitive decisions to occur (McGrew, 2009; Taylor et al., 2000).

Stamina. It is the lack of variability in a subject's response time speed in a dynamic and static environment. This is the ability to maintaining a sustained effort, and consequently maintaining the speed of mental processing (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Static Environment. This refers to a non-changing environment that requires watchfulness and vigilance but no overt responses from the human operator. The human operator is in a state of inhibition when working in this environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Static Vision. It is visual processing that occurs in the static environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Vigilance. It is the maintenance of attention required to respond to a change in the environment (a state of inhibition) such as responding to a target. In the environment the mind can wander, the subject must maintain his or her attention in order not to miss a target (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Visual attention (VA). It consists of human visual perceptiveness and attentiveness (Brain Train, 2010; Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994).

Visual or Visio- spatial working memory (VSWM). It is WM that contains visual and spatial information that is stored in the visuospatial sketchpad in the mind (Baddeley, 2006), this immediate memory can be thought of as a workbench where material is continuously being combined and transformed.

Working memory (WM). Working memory is a limited storage capacity of memory of information that cannot retain data for long periods of time and decays rapidly after one minute unless the individual stimulates other cognitive processes to retain the information (McGrew, 2009).

Summary

Static and dynamic visual processing is comprised of three specific variables: visual attentiveness, perceptiveness, and visuospatial memory (Christensen et al., 2013; Endsley, 2012; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). Consequently, this project tested the predictive value of these variables as factors between a particular task to be performed and the eventual outcome of situation awareness. A field experiment in the paradigm of neuroergonomics, (Parasuraman, Christensen, & Grafton, 2012) employing quasi-experimental repeated-measures (within-participants) design, was used for this study. Further inquiry involving visual cues should clarify the role of these abilities as independent and or mediating variables in order to make theory-driven predictions for situation awareness (Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). This affects society worldwide.

Chapter 2: Literature Review

Introduction

This literature review is intended to expand further on the elements of existing psychological theory and research that are relevant to the work. Following an introduction to neuroergonomics, situation awareness will be reviewed as a central concept. The discussion then proceeds with the basic component processes that are essential to situation awareness, including general cognition, visual perceptions and attention, visuospatial working memory, and mental workload. The review will seek to highlight where this work was needed and where it will expand the body of knowledge in these areas, and identify potential real-world implications.

Documentation

For this 40 page literature review, electronic searches, in-person trips to university libraries, and face-to-face interviews with subject matter experts were completed and peer reviewed articles were located using EBSCOHost, PsychINFO, ProQuest Research Library, Science Direct, Google Scholar databases, the USAF AFRL library, the DoD DTIC, the AFIT, University of Dayton, and Wright State University Libraries. These search engines, libraries, and techniques were chosen for their extensive compendium of appropriate material and information. Search terms included: workload, neurology, stimuli, neural network, attention, cognition, visual perception, vision, human brain, memory, situation awareness, TMSA, AAT, MRT, SEEV, aviation, pilot, cockpit, UAV, display, HUD, HDD, USAF, aircraft crashes, CFIT, the human eye, brain, working memory, theoretical physics, and psychological theory. Additional searches were conducted using the reference sections of articles located through electronic searches.

The literature review that follows has been organized into 22 sections: (a) Neuroergonomics, (b) Cognitive Situation Awareness, (c) The Theoretical Model of SA (TMSA), (d) Critiques of the TMSA, (e) Studies Involving Vision, Prediction, and Situation Awareness, (f) Cognition, Perception, and Memory, (g) The HUD, Situation Awareness, and Visual Attention, (h) Recent HUD Research, (i) Work Load (WL), (j) Current Independent View of the Multiple Resource Theory (MRT), (k) Recent Research Measuring Pilot Mental Workload, (l) The Salience Effort Expectancy Value (SEEV) Model, (m) The SA and WL Relationship. (n) Vision, (o) Attention and Motion Perception, (p) Objective of the Display, (q) Relating Visual Perception, Neuropsychology, and SA (r) Display Design, (s) Cognitive Modeling, and (t) Summary.

Neuroergonomics

Neuroergonomics is a rapidly expanding, interdisciplinary area of research whose purpose is to enhance knowledge of brain activity, function, and human behavior as encountered at work and in natural settings (Parasuraman, Christensen, & Grafton, 2012). It is integrated research between psychology, cognitive neuroscience, human factors, engineering, computer science, ergonomics, and medicine (Lees, Cosman, Lee, Fricke, & Rizzo, 2010). For example, neuroergonomics can focus on the psychology of perceptual and cognitive functions and actions in relation to actual technologies (Parasuraman et al., 2012). A premise of this multidisciplinary approach is that knowledge in the psychological sciences will be enhanced. *Neuroergonomics: The Brain at Work* (Parasuraman and Rizzo, 2008) indicated this composite exploration is growing and is being driven by the emergence of information-saturated information display (ID) technology that is now being utilized by humans for activities requiring divided attention and multitasking (Parasuraman, Christensen, & Grafton, 2012). Neuroergonomics provides a novel approach as a contemporary perspective in science, and field research of human situation awareness is an integral part (Lees et al., 2010; Parasuraman et al., 2012; Parasuraman & Rizzo, 2008; Parasuraman, Sheridan, & Wickens, 2002; Parasuraman & Wilson, 2008; Wilson, Estepp, & Davis, 2009). This work adopted a neuroergonomic approach. It is fueled by the demands of data-dense display technology, such as the information displays in aircraft cockpits (HDD, HUD) (Parasuraman, Christensen, & Grafton, 2012).

Cognitive Situation Awareness

Cognitive situation awareness is often discussed using philosophical concepts (Blandford & Wong, 2004; Dekker & Hollnagel, 2004; Elliott et al., 2009; Gorman, Cooke, & Winner 2006; Jodlowski, 2008; Nullmeyer, Herz, & Montijo, 2009; Rousseau, Tremblay, & Breton, 2004; Shelton, et. al, 2009). For example, Dekker and Hollnagel (2004) refer to most situation awareness theories as nothing more than *folk models*. They state that contemporary theories of situation awareness are not sufficiently articulated to explain the details. Various theories superficially seem to be useful scientific models, yet just below the surface they lack an *articulated mechanism*.

Situation awareness is currently viewed as a complicated tangible that exists and necessitates a keen sense for visual cues (Billingsley, Kuchar, & Jacobson, 2001; Endsley, 2012; Parasuraman, Sheridan, & Wickens, 2008). Endsley's (2012) Theoretical Model of situation awareness (TMSA) submits there are a total of three levels for situation awareness: a) perception (Level 1), b) comprehension (Level 2), and c) projection (Level 3). It is difficult to define situation awareness in more detail without reference to a particular task. For piloting, situation awareness could be described as the cognitive awareness level by the pilot as it relates to aircraft flight (Tsang & Vidulich, 2003, 2006; Vidulich & Tsang, 2012). At the fundamental level of situation awareness, the pilot needs to perceive relevant information (Endsley, 1995a, 1995b) accurately. Pertinent to this study, situation awareness can be described as a function or product of ID effectiveness and neurocognitive elements such as mental work load (J.C. Christensen, personal communication, Jan 10, 2012).

The concept of mental workload in the context of this study is the level of demand imposed by tasks on the pilot's limited mental resources (Wickens & Hollands, 2000). Abstractly, mental workload can reflect a subjective experience of mental effort (Dekker & Hollnagel, 2004). It is related to both demand and cognitive capacity (Wickens, 2008). The demand is imposed by mental tasks on the human, whether considered as single or multiple (Wickens, 2008). Workload in aviation is environment driven; therefore, it is driven by the stimulus and activity involved, and it is not something that is necessarily self-paced. In straightforward and simple terms, workload is the level of mental effort a given individual puts forth when performing tasks such as aviating, which consume cognitive capacity. In summary, workload is a function of both task difficulty and individual capability; as individual capability varies so the same task will produce different levels of mental workload in different individuals (J.C. Christensen, personal communication, Jan 10, 2012).

Neuroergonomic methods provided the framework for this field study integrating subjective & objective measures. In keeping with the fundamental concept of neuroergonomics, this study took a multidisciplinary approach to studying the brain at work in the cockpit, including measuring workload as a means to assess situation awareness predictors. Adopting neuroergonomic methods, this study examined the effects of ID design in actual flight with neurocognitive factors as intervening variables. In general, a combined approach including psychophysiological measures has been identified as having strong potential for improving our understanding of situation awareness and workload, and the relationship between the two (Bailey et al., 2011; Campbell, 2010; Campbell, Castaneda, & Pulos, 2010; Crawford & Neal, 2006; Douglas, Aleva, & Havig, 2007; Flight Safety Foundation, 2009; Geiselman & Havig, 2011; Harbour, Christensen, Estepp, & Gray, 2012; Harbour, Hudson, & Zehner, 2012; Kim, 2009; Kramer et al., 2005; Wickens, 2008; Wickens, Levinthal, & Rice, 2010).

The Theoretical Model of SA (TMSA)

The Theoretical Model of Situation Awareness (TMSA) as described by Endsley (1995a) combines narrative accounts of processes along with the emphasis on empirical tests of feasibility (Figure 1). Endsley's framework is grounded in hierarchical levels of situation awareness and is based on information processing. Level 1 situation awareness contains the perception and processing of cues. An example could perceive the environment and a display yielding spatial awareness (Endsley, 2012; Wickens, 2008; Wickens et al., 2008). Level 2 situation awareness is the comprehension of the current situation by utilizing the information gained from Level 1 situation awareness perceptions combined with individual background knowledge, thereby creating a situation model (Endsley, 2000a, 1995a; Wickens, 2008). Level 3 situation awareness is the utilization of the situation model to project and predict the future state (Endsley, 1995a, 2000b; Sulistyawati, Wickens, & Chui, 2011; Wickens, 2009). Endsley's (1995a, 2002a) view of situation awareness is often utilized as the basis for research in areas such as system displays and military operations (Eid, Johnsen, & Brun, 2004; Sulistyawati, Wickens, & Chui, 2011).

Situation awareness may be defined with greater specificity for a particular task or domain; as this study focused on flight operations, situation awareness was considered in this context. Level 1 situation awareness is the foundation for achieving situation awareness. In aviation, it begins with how the pilot perceives the critical cues in the environment (Endsley, 1995a, 1995b, 2012) needed to successfully fly and achieve mission goals. Aircraft flight is described by six degrees of freedom; therefore, an aspect of situation awareness is the cognitive awareness by the pilot of those six degrees (Wickens, 2002). The six degrees of freedom in flight are the attitude of the aircraft in pitch, yaw, and roll, and the location of the aircraft in altitude, latitude, and longitude (Wickens, 2002). More specifically, because those six degrees are always in a constant state of change and projection into the future is a key part of situation awareness, then full situation awareness would be possessing knowledge of the partial derivative of the six degrees with respect to time. This aircraft and aviation situation awareness knowledge also includes the awareness level of the configuration of the aircraft, and the location of other aircraft (past, present, and future). Knowledge of the six degrees of aircraft flight is considered primary flight information (PFI) and is conveyed to the pilot via cockpit information displays.

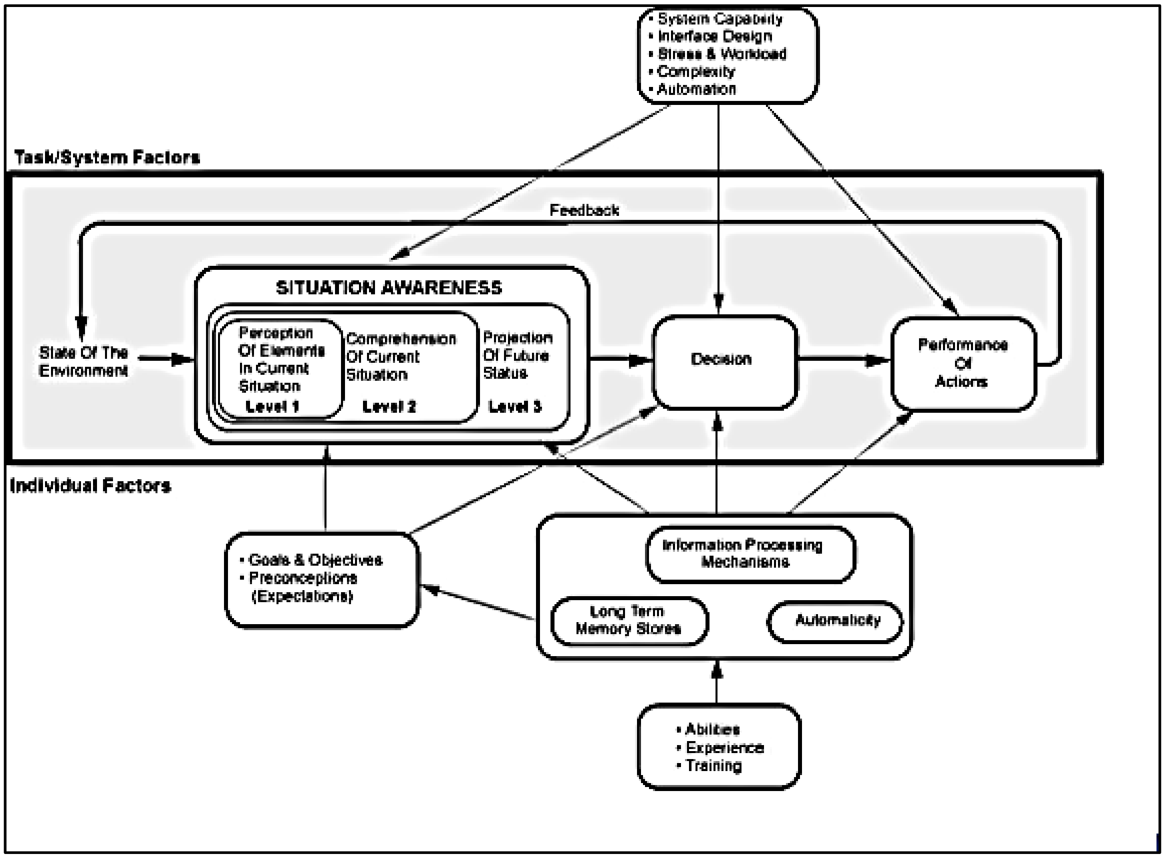

Figure 1. Theoretical Model of situation awareness (adapted from Endsley, 1995b). The three levels of situation awareness are depicted with respect to individual capabilities, system capabilities, and performance. This study addresses the theoretical links between abilities, information processing, situation awareness and performance.

Jones and Endsley (1996) found that the vast majority (77%) of human errors in aviation involving problems with situation awareness stem from difficulties with the perception of needed information, which is the formation of Level 1 situation awareness (Figure 2). In the flying environment, pilots must make time critical decisions, therefore efficient information processing becomes paramount and the ID should be designed so that the pilot can easily perceive the PFI in order to safely aviate.

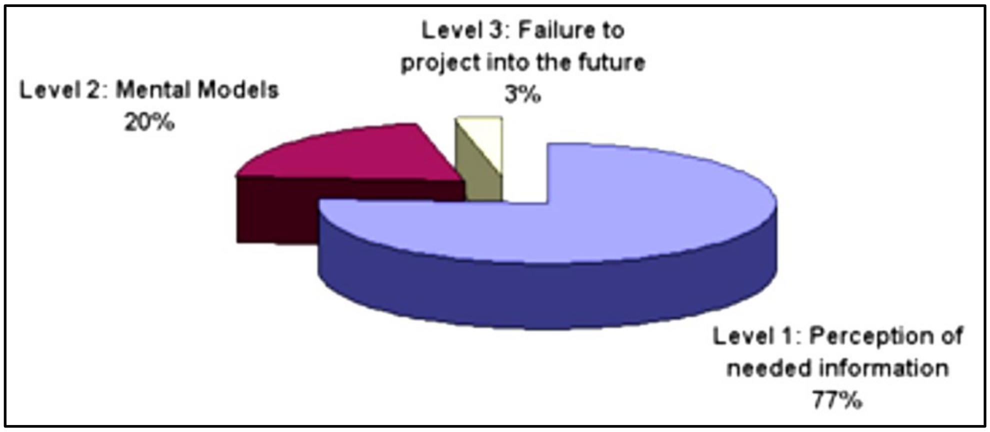

Figure 2. Errors in aviation attributable to situation awareness (Jones & Endsley, 1996). A significant majority of errors are associated with perception, which for aviation is primarily visual.

A reduction in attention due to distractions or increased effort, which can result in increased workload, has been found to undercut situation awareness especially in flying tasks and poses one of the most significant challenges to maintaining situation awareness (Endsley, 2012).

Critiques of the TMSA

There are at least 34 different and or varying definitions of situation awareness with little consensus in the scientific community (Beringer & Hancock, 1989; Breton & Rousseau, 2003; Cass, 2011; Jodlowski, 2008; Rousseau, Termlay, & Breton, 2004) and the same existed for the exact composition of situation awareness to include its predictors (Blandford & Wong 2004; Dekker & Hollnagel, 2004; Elliott et al., 2009; Gorman, Cooke, & Winner 2006; Jodlowski, 2008; Nullmeyer, Herz, & Montijo, 2009; Rousseau, Tremblay, & Breton, 2004). Therefore, there was not a specific mathematical equation or variable relationship that included situation awareness predictors. There are at least two theoretical alternatives to TMSA (Stanton, Chambers, & Piggott, 2001): the *theory of* *activity model* to describe situation awareness (Bedny & Meister, 1999)- and the *perceptual cycle theory model* that is an ecological approach (Niesser, 1976; Smith & Hancock, 1995). These theories diverge in their foundational psychological construction (Salmon et al., 2008). The *theory of activity model* varies from the TMSA in that it describes situation awareness using eight functional blocks and posits that the degree to which blocks are engaged is contingent upon the character of the task and the individual's goals (Stanton et al., 2001). The *perceptual cycle theory model* is an alternative view of situation awareness, in that it is not dependent upon the domain or the individual, rather it is a function amidst the interaction of the domain with the individual (Stanton et al., 2001).

As any important concept should, situation awareness has spawned some degree of rigorous academic deliberation (Dekker & Hollnagel, 2004; Dekker & Woods, 2002; Parasuraman, Sheridan, & Wickens, 2008; Patrick & Morgan, 2010; Wickens, 2008). One key point of contention is whether situation awareness refers to the *process* of gaining awareness, the *product* of it, or a combination of the two (Salmon et al., 2008). The answer to this question then influences opinions on how to best measure situation awareness; there are a plethora of approaches to assessing situation awareness and copious associated theoretical debate. The continuing debates over situation awareness illustrate the need to refine the theory (Dekker & Hollnagel, 2004; Parasuraman, Sheridan, & Wickens, 2008; Patrick & Morgan, 2010; Wickens, 2008). Consequently, there simply was no established *theory as law* of situation awareness; it has been described as a *theory as narrative*, and therefore, no specific mathematical equation or variable relationships include situation awareness predictors.

What is known is that situation awareness plays a vital role in dynamic decision-making environments (St. John & Smallman, 2008). However, further controversy existed regarding specific details of TMSA. Endsley's theory emphasizes perception and comprehension of the environment amid projection into the future; however, it does not contain enough granularity or accuracy in the area of human perception (Elliott et. al., 2009; Gorman et al., 2006; Jodlowski, 2008; Stanton et al., 2001; Wickens, 2008). The TMSA does not emphasize reflective relationships between mental models and knowledge of the present system. There were no specific neurocognitive antecedents or predictors of SA. The theory is consequently incomplete, lacking, and requires this for a needed advancement (Ellis & Levy, 2009; Elliott et al., 2009; Endsley, 2012; Gillan et al., 2009; Gugerty, in press; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Lau, Jamieson, & Skranning, 2013; Proctor & Vu, 2010; Sulistyawati, Wickens, & Chui, 2011; Vidulich & Tsang, 2012; Wickens, 2008; Wickens & McCarley, 2008).

In order to design better control systems and information displays, it is necessary to understand the nature of situation awareness (Blandford & Wong, 2004; Pritchett & Hansman, 2000). Situation awareness formation should be articulated by constituent psychological mechanisms (Dekker & Hollnagel, 2004). Situation awareness needs a level of detail to account for psychological mechanisms required to connect features of the sequence of events from the start of perception to the outcome of action (Dekker & Hollnagel, 2004; Endsley, 1998, 2006b). Situation awareness is a predictor of flight performance (Durso, Truitt, Hackworth, Crutchfield, & Manning, 1998) and enhancing pilot situation awareness improves flight performance and allows for increased safety and efficiency of air and taxi operations (Crawford & Neal, 2006).

In conclusion, prior research was incomplete with regards to the exact role of visual processing abilities; current and future research to refine measurement of these abilities must be accomplished. Seminal work performed by Crawford and Neal (2006), and Gorman, Cooke, and Winner (2006) indicated the need for additional research examining the impact of HUD usage on situation awareness in flight, in particular, with respect to the prediction of situation awareness. The critical variables underlying the formation of situation awareness as well as the possible relationships among these variables needed to be identified.

Studies Involving Vision, Prediction, and Situation Awareness

Situation awareness is among the most important cognitive abilities required successfully to perform complex cognitive tasks such as piloting an aircraft or driving a car (Tirre & Gugerty, 1999). Case studies and analysis (Kim, 2009) of existing databases have confirmed that a reduction in situation awareness is a significant precursor to aviation performance failures. This section covers 15 quantitative experiments and ten research articles that have illustrated the need and attempted to discover the detailed links between vision, cognition, predictability, and situation awareness over a 15-year period up to the present day, illustrating the continuing need to fill this gap in the TMSA. Tirre and Gugerty (1999, 2000) performed situation awareness experiments that are especially relevant to the current work. In their study, a driving simulator was utilized in an attempt to derive a set of individual cognitive attributes that correlated with situation awareness. Participants completed a number of scenarios in the highway driving simulation (PC-

DriveSim) that varied the type of traffic hazard encountered. The outcome yielded six attributes that were correlated with a situation awareness composite score, together accounting for fifty-percent of the variance. The situation awareness composite score was a combination of accuracy in answering memory probes at and a performance score (derived from driver control responses to hazards), weighted at 2/3 and 1/3 respectively. As a result of this weighting, the majority of the score was based on probes (surveys) that required the stopping of the driving simulator followed by the participant answering a series of questions on two different surveys (based on Endsley's SAGAT technique, 1995b). The two debatably subjective survey measures were time-to-passage (answering "which car" will overtake "which car") and scene interpretation (at the end of a moving scene answering questions about other vehicles' location and who was the erratic driver). The performance probe, which was based on the "correctness" of actual driver's inputs, was the only orthodox objective measure.

In their first experiment, there were 88 participants, with 61 males and 27 females ranging in age from 18 to 30 years. The computer-administered cognitive battery CAM 4.1 measured the level of working memory utilizing a digit-span procedure. Visual processing ability was estimated by approximating search ability based on three subtests of the Air Force Officer Qualification Test (AFOQT): block counting, table reading, and scale reading. The AFOQT is a pencil and paper timed test that estimates visual search ability, thus capturing a portion of dynamic visual processing. Significant correlations were found between the situation awareness measures and working memory, visual search, and temporal processing. Specifically, the multivariate analysis yielded results for working memory as part of a composite score for situation awareness at $r = .44$, $p < .001$, correlated with both hazard detection and blocking-vehicle detection. Additionally, correlations existed between visual search as part of a composite score for situation awareness and hazard detection, $r = .22$, $p < .05$, and $r = .21$, $p < .05$ for blocking-vehicle detection. However, due to a lack of sensitivity in the largely pencil and paper measurement technique and limited set of visual ability measures; this does not completely clarify the relationship between visual capacity and situation awareness.

Based on multiple regression analyses, dynamic visual processing, visual search, time-sharing, and temporal processing were the attributes that made significant unique contributions. As stated by the authors, however, precise knowledge of how, in what way, and or why they affected situation awareness was and is unknown (Tirre & Gugerty, 1999). In this seminal work, the other two discovered attributes, static visual processing and working memory, were corollary but with " mixed evidence," (Tirre & Gugerty, 1999, p. 18) likely due to chosen experimental procedures in the final experiment. The precision of the Tirre and Gugerty study was likely limited due to the reliance on pencil and paper tests (e.g. the AFOQT for visual abilities and ASVAB for working memory, circa 1990) that could be considered obsolete for measuring those factors. Computerized testing with precise reaction time measurement was used in this dissertation in order to improve accuracy and sensitivity as compared to previous work.

In the final experiment, Tirre and Gugerty added additional working memory (quantitative and verbal via the pencil and paper ASVAB) and visual processing tests. These visual processing tests included dynamic visual tests via a road sign test and a directions detection test along with a computerized portion of the AFOQT, and static visual testing via an unchanging stimuli such as searching for a target in a visual array test, and the pencil and paper AFOQT. However, it fell short on testing visual spatial working memory ability without it being mixed with perceptual-motor coordination and auditory testing via the computer-administered cognitive battery CAM 4.1. Likewise, the final experiment did not test basic visual processing elements such as vigilance, attentional focus, response inhibition, and reaction time. For the last experiment, 128 participants were included with 64 males and 65 females ranging in age from 17 to 35 years of age. Situation awareness was measured by the level of driving performance in the simulator. The working memory (WM) and situation awareness results as part of the multivariate analysis were inconclusive with little to no correlation ($r = .02$, $p>.05$), likely because the researchers did not measure WM in the same manner as the previous experiment; instead, the general aptitude component of the Armed Services Vocational Aptitude Battery (ASVAB) test was used. The general aptitude component of ASVAB was used as a proxy for WM, however the lack of consistent results as compared with the researchers' own previous experiments using visual WM tests suggests the general aptitude component is not sufficiently specific. In this dissertation, the positive results obtained were likely contingent on the use of precise cognitive ability testing focused on those abilities tapped by the task.

The multivariate correlations between situation awareness on one hand and dynamic visual processing and static visual processing on the other were found to exist in the last experiment, however the correlations were not significantly different from each other, $r = .29$ and $r = .18$, respectively, $t(108) = .88$ $p < .4$. Tirre and Gugerty (1999) indicated that even though this research opened the door to assessing candidate cognitive factors for situation awareness, their work was a first exploration, and they hoped that improved understanding of the role played by these abilities in forming and maintaining situation awareness would be achieved in future research.

In order to attempt to understand vision's role in SA formation further, Wickens (2008), researched particular characteristics and cues in a display that can influence situation awareness. Wickens (2008) investigated the effects of a synthetic vision system (SVS) and a highway-in-the-sky (HITS) presented in the pilot’s cockpit on a display to determine if these cause change blindness in the environment beyond the cockpit, which can be an aspect of what is often called attentional tunneling. Seven quantitative experiments and studies were reviewed by Wickens that utilized high fidelity simulators with instrument rated pilots flying with an SVS display with and without HITS. Numerous standard approaches and landings were performed, 50% with HITS. The percentage of pilots who failed to detect an unexpected outside environment event when flying with a SVS HDD without HITS was only 17%, while with HITS it was over twice as large at 38%. The HITS added a very compelling 3D command to the display that clearly was responsible for attention tunneling by the pilot, more so than the SVS image alone, a 3D status display without HITS (Wickens, 2008). Apparently, those pilots who failed to detect an unexpected event lacked complete level 1 situation awareness; consequently, one may conclude that display design and specifically attentional tunneling influence situation awareness. However, the degree to which improved visual attention prevents attentional tunneling, hence improving situation awareness, was not addressed in that work.

Applied Attention Theory (AAT) (Wickens & McCarley, 2008) indicates that visual attention control, scanning, information sampling, visual search, spatial attention and displays play a role in pilot mental workload, which in turn would imply an influence on situation awareness as well. Wickens (2008) discovered that visual search and attention were unique factors for workload. An understanding of visual processing factors operating in dynamic environments related to attention is incomplete (Wickens & McCarley, 2008, p. 38).

Elliott et al. (2009) performed a deep dive assessment of quantitative research bringing into play visual displays, information providing auditory modalities, and vibrotactile interaction. Even though this dissertation's focus is on vision only IDs, the Elliot deep dive assessment brought to light gaps and needs in the area of vision and situation awareness. Studies meeting assured criteria were reviewed and evaluated, such as for research design and characteristics, and cue information complexity for spatial awareness. One of the comparisons that mark this study relevant and needed is the comparisons between visual cues and a multimodal combination of tactile and visual cues, or tactile cues alone representing the same information.

One of the Elliot et al. (2009) hypotheses indicated that tactile cues would not be effective when replacing visual cues, and this was to some extent supported. Due at least in part to the conservative random effects model used for statistical testing, the results were not significant. Even though the effect of replacing visual cues with tactile cues was large ($g = 0.95$, SE = 0.22), significant variation prevented a statistically significant result (Qtotal = 288.89, $p < 0.01$). This recent finding by Elliot reemphasized that vision is the most dominant sense when it comes to influencing situation awareness (Wade & Swanston, 2012), consequently further elucidating the visual attributes of situation awareness will have the greatest impact.

Elliot et al. (2009) provide additional knowledge to build upon when researching visual cuing, displays, and the neurocognitive factors involved in Level 1 situation awareness prediction. This study identified areas in need of further investigation, specifically work on mediating factors and refining guiding principles to determine when, where, why, and or how cues come into play to support human performance in demanding or complex environments. Future studies need to further investigate and refine theory-driven predictions for workload and demands for attentional abilities to include visual cuing (Elliot et al., 2009; Strater, Riley, Faulkner, Hyatt, & Endsley, 2006). As concluded by Wickens (2008), additional experiments should be performed examining individual human differences, principally with regard to attention skills, and task performance as related to situation awareness and workload.

The research performed by Jen-li, Ruey-Yun, and Ching-Jung (2013) examined display design for unmanned aerial vehicle (UAV) monitoring, and its effects on operator situation awareness, performance, and mental workload. UAV monitoring can be demanding on visual attention. This quantitative research involved 56 participants that were randomly selected and assigned to either a situation-augmented display or a conventional display condition to work on UAV monitoring tasks. The operator in UAV flights has to rely primarily on vision in this agent-based system, consequently the question remains to be what role does display design and human visual abilities play in the human-robot interface in order to enhance situation awareness (Jones, Connors, & Endsley, 2011), again illustrating the need to expand the TMSA. The purpose of this study was to examine these effects in the UAV monitoring environment (Jen-li, Ruey-Yun, & Ching-Jung, 2013).

College students volunteered to participate in the study; they were not trained aviators, UAV operators, or USAF pilots and thus we may expect significant variance in prior experience and expertise. This may have been a factor contributing to their need for a relatively large sample of 56 individuals. Fifty men and six women provided an equal number of observations in each display condition. The average age of the participants was 21.82 (SD = 4.03, range: 16–33). For these experiments, there were two display types utilized: the conventional display vs a situation enhanced and augmented display. The conventional display served as a comparison or control for the situation-augmented display. The conventional display system was modeled after the current FAA display models. The situation-augmented display incorporated a projected flight trajectory to aid visual processing.

The study sought to measure the difference in operator performance as a function of the two different displays. Abnormal events were randomly presented to the participant, and then corresponding errors were measured. UAV operator error rate was submitted to a 4-way ANOVA with repeated measures. This analysis showed that only the main effect of number of abnormal events ($F_{3,162} = 28.46$, $p < .001$, $\eta 2 = .35$) and block ($F_{2,108} = 30.74$, $p < .001$, $\eta 2 = .36$) were significant. The main effect of block could be due to learning effects within the study, a possible consequence of the non-expert participants. As expected, the error rate increased from 48.4% (SE = .016), 50% (SE = .016), 50.5% (SE = .016), to 55.7% (SE = .016) as the number of abnormal events increased from 0, 1, 2, to 3, illustrating that the manipulation of workload (task difficulty) was successful. The only statistically significant effect related to display type was a display type by number of abnormalities by block interaction ($F_{6,324} = 2.93$, $p < .011$, $\eta 2$

= .05). In order to test the statistically significant three-way interaction of display type by number of abnormalities by block on the error rate, separate two-way ANOVAs were performed for each block. The only statistically significant effect regarding the display type error rate was a display type by the number of abnormalities relation ($F_{2.969, 160.327} = 6.06$, $p < .001$, $\eta^2 = .101$).

Nonetheless, multiple comparisons between means showed no significant differences between display types in the different number of abnormalities conditions. The hypothesis that the situation-augmented display would decrease the error rate in a UAV-monitoring task was not supported. However, and as a very important note the error rate remained near 50% after 24 trials of practice. This high error rate suggests that the UAV-monitoring task was extremely hard for these novice participants (as would be flying an aircraft). It may have been possible to observe more of the potential benefit of the situation-augmented display if participants had been more experienced. Clearly, this shows that using a trained homogeneous group such as USAF pilots would have produced results that were more realistic and meaningful, while requiring a smaller sample size. For this study, flight completion time was also evaluated (the faster, the better), as a function of display type used. Results of a 4-way ANOVA supported all the predictions: the main effects of display type ($F_{1,54} = 4.871$, $p < .032$, $\eta^2 = .08$), the number of abnormal events ($F_{3,162} = 22.14$, $p < .001$, $\eta^2 = .29$), the number of light signals ($F_{1,54} = 14.06$, $p < .001$, $\eta^2 = .008$), and the block ($F_{2,108} < 40.21$, $p < .001$, $\eta^2 = .43$) were all statistically significant. The main effect of display type supports the hypothesis that the situation-augmented display would improve UAV-monitoring performance in terms of shortened flight completion time (*M* = 100.37 sec./trial, *SE* = 3.68), when compared to the conventional display (*M* = 111.85 sec./ trial, *SE* = 3.68).

Most notably, the main effect of display type indicated that participants using the situation-augmented display were 2.67 sec. faster in abnormality detection (*M* = 5.67 sec., *SE* = 0.50) than those using the conventional display (*M* = 8.36, *SE* = 0.50), suggesting that the effects of situation-augmented display on abnormality detection were robust across different workloads and noise levels.

In regards to mental workload, results of the t-tests on participants' un-weighted total scores and the six sub-scores on NASA–TLX questionnaire (Charlton et al., 2002) showed no statistically significant difference between the two types of displays (t's $<$ 1.55). In general, the UAV-monitoring task appeared to place a higher load on mental demands (*M* = 17.16, *SD* = 2.37), effort demands (*M* = 15.36, *SD* = 3.56), and speed demands (*M* = 14.80, *SD* = 3.76) than performance demands (*M* = 11.09, *SD* = 4.69), physical demands (*M* = 11.07, *SD* = 5.71), and frustration experienced (*M* = 10.02, *SD* = 6.77). Reducing UAV operators' mental workload is thus important in the UAV-monitoring task. The situation-augmented display was not sufficient for alleviating the operator's mental workload in UAV monitoring.

These results illustrated that compared to the conventional display, the effects of situation-augmented display on flight completion time and abnormality detection time were robust across different workloads but error rate and perceived mental workload were unaffected by the display type. With the increasing complexity of new automation technology, discovering the correct visual processes to aid the control operator's situation awareness remain a significant challenge for the field. An important point gained from this study is that the Level 1 SA from the TMSA still presented problems for these researchers in that they had difficulty in measuring the effects between operator visual abilities and display usability (Jen-li et al., 2013). More studies are needed to address these unresolved and outstanding issues (Jen-li et al., 2013) expanding the TMSA.

Objective measures of situation awareness and workload, conceivably in actual flight, would most likely provide the basis for this deeper understanding of situation awareness (Harbour et al., 2012), as will, testing for participant's levels of visual abilities beforehand. Given these findings, the most important predictive measures for future studies would be dynamic visual attention and spatial tests. For the past decade, researchers have been attempting to unravel these important mysteries. Tirre, Elliot, Wickens, Parasuraman, Christensen, Vidulich, Tsang, Jen-li, Gugerty, and many others have been performing research to further solve this mystery and with each successive article, the field has gotten closer to the answers, but there was more to be done (Endsley, 2012; Vidulich & Tsang, 2012).

Cognition, Perception, and Memory

In a broad sense, cognition is thought or collective thoughts; more specifically, it is the human process that is mental activity, which utilizes thoughts for acquiring, processing, storing, transforming, and using knowledge (Matlin, 2008). Elements of cognition include sensation and perception, imagery, memory, reasoning, and problem solving (Blake & Sekuler, 2006).

Situation awareness does require input processing such as cue recognition, in order to make a situation assessment and prediction upon which good choices can be based (Artman, 2000; Parasuraman, Russo, Wickens, 2008), and cue recognition involves cognition, perception, and memory processes. Durso et al. (2007) point out that through the bottom-up process of perception, information in the environment is indicated by cues, followed by the top-down process resulting in the development of a situational model integrating this into context. The top-down process involves a higher order of cognitive thought utilizing visual-spatial working memory (Ericsson & Delaney, 1999; Ericsson, Patel, & Kintsch, 2000; Hameed, Jayaraman, Ballard, & Sarter, 2007). In order to construct a representation of the environment, humans must develop an *event-base* around them (Durso et al., 2007). Therefore, if situation awareness develops, in the same way, as discourse comprehension, event-base development begins through a strictly bottom-up process driven by sensory information. Therefore, for Level 1 in situation awareness (perception) to occur correctly it is vital to the initial stage of visual perception and the processing of that information to also occur properly. Top-down processing is utilized to allow assigning the appropriate meaning in a particular context to the visual information, which requires WM, specifically visual-spatial WM (Durso et al., 2007; Matlin, 2008) for spatial information.

This would entail three variables: visual perceptiveness, visual attentiveness, and visual-spatial working memory (WM) (Blake & Sekuler, 2006; Brain Train, 2010; Matlin, 2008; Carlson, 2010). These may be summarized as: a) did the pilot see it at all, b) did the pilot attend to it, and c) did the pilot encode it in memory such that he or she could use it in building a situation model. An understanding of visual processing factors (such as independent or moderating or mediating/intervening variable/s) operating in dynamic environments was incomplete (Crawford & Neal, 2006; Elliott et al., 2009; Tirre & Gugerty, 1999; Wickens, 2002). This suggested that the inherent neurocognitive factors of visual attention (perceptiveness and attentiveness) and visual-spatial working memory, as part of a theory may explain their support for the development of situation awareness.

Working memory has a relatively small capacity and only contains a small amount of information that the human is actively using at the time, in relation to using it to perform work (Zook, Davalos, DeLosh, & Davis, 2004; Vicente, 1992). Working memory can be lost within thirty seconds unless it is repeated (Charness, 1976; Chase & Simon, 1988; Matlin, 2008). Baddeley (2006) indicates working memory performance influences the ability of the central executive to manage work on two tasks at the same time, or to inhibit a task response. Working memory capacity must be shared between current activities and temporary storage of intermediary results and recently encoded data (Copeland & Radvansky, 2004; Daneman, & Carpenter, 1980). Its capacity varies considerably across individuals, and it is the central bottleneck in information processing (Engle, Carullo, & Collins, 1991). According to Baddeley, visual and spatial information is stored in a limited visuospatial sketchpad; performing two visuospatial tasks simultaneously will cause interference with each other (Sohn, & Doane, 1997, 2000, 2003). Therefore, visuospatial working memory should be critical to situation awareness.

The HUD, Situation Awareness, and Visual Attention

As discussed above, Endsley stated (1995a) that the perception of the elements in the environment is the first level in situation awareness. In flying tasks, the pilot has to reference the cockpit Information Display (ID) to perceive and comprehend primary flight information. A HUD should enhance pilot perception (level 1) and comprehension (level 2 situation awareness) of the environment to facilitate projection of his or her status in the near future (level 3 situation awareness), (Crawford & Neal, 2006; Flight Safety International, 2009; Gorman, Cooke, & Winner, 2006). The foundation for achieving situation awareness in aviation thus begins with how the pilot perceives the critical cues in the environment (Endsley, 1995a, 1995b) to fly successfully and achieve mission goals. To enhance situation awareness, the ID design should be salient and easy to see in order to minimize demands on the pilot's attentional abilities. Effective ID design should, therefore, benefit overall task performance, though this effect is expected to be mediated by pilot visual skills. Gorman, Cooke, & Winner (2006) and Crawford & Neal (2006) indicate that future research needs to uncover the factors that predict situation awareness and discover how they interact with pilot abilities in apprehending the information offered by cockpit IDs.

A subjective evaluation derived from flight simulator data (Flight Safety Foundation, 2009; Kim, 2009) suggests that many of the accidents attributed to CFIT may have been prevented had a HUD been installed in the cockpit. That study assessed what may have been a likely outcome assuming that a properly operating HUD, correctly operated by a trained crew, had been in use on each accident aircraft (Flight Safety Foundation, 2009). HUDs are intended to lower workload and increase situation awareness (FSF, 2009). The proper operation of the HUD system may be impaired due to poor placement and visibility, particularly in aircraft that did not originally come with a HUD (Hudson, Zehner, Harbour, & Whitehead, 2011). This study included conditions both with and without a HUD available.

Recent HUD Research

The HUD manipulation was incorporated into this study as a real-world means of varying task difficulty with consequent impacts on situation awareness. Harbour, Hudson, and Zehner (2012) performed research on head up display (HUD) placement to determine pilot visibility. Based on physical characteristics of the HUD and a distribution of pilot eyes around the design eye point, the loss of information visibility was mapped and predictions made regarding possible psychological refractory periods induced by switching attention between displays (see Table 1 Pilot Visibility (View) & Table 2 Psychological Refractory Period).

Table 1

Pilot Visibility (View)

	FOV	**LOS**
HUD	**No Loss**	**Up to 5 degrees up**
HDD	**No Loss**	**35 degrees down**

Table 1 illustrates the FOV and LOS as a function of display used.

Table 2

Expected Psychological Refractory Period

	FOV	**LOS**
HUD	**No PRP**	**No PRP**
HDD	**No PRP**	**PRP**

Table 2 illustrates the PRP associated with the display used as a function of FOV and LOS.

The study recommended that more research in this area should be accomplished, utilizing neuroergonomic techniques, in the actual aircraft in-flight. The effects of varying spatial locations of information displays (ID) in addition to individual differences in visual perception and attention abilities coupled with the effects on pilot workload and situation awareness should be researched (Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens & McCarley, 2008).

Work Load (WL)

The Federal Aviation Administration defines mental workload as the psychological and physiological demands that occur on a human while performing a task or multiple tasks (FAA, 2011). Mental workload can be conceptualized as being in one of the two regions of task demand level (Wickens & Hollands, 2000). The first is when the demand is less than the available capacity of resources, therefore, there are resources not used in the task performance. The second region is one in which the demand exceeds the capacity; therefore, performance will break down (Wickens, 2008). The challenge lies in determining the boundary between these regions (Wickens, 2008; Yerkes & Dodson, 1908).

Flying a modern military aircraft is indeed operating a complex system, performing several tasks at the same time that increase pilots' mental workload. Accurate mental workload measurement is critical because workload significantly affects human performance, and a better understanding of the relationship between primary abilities, mental workload, and situation awareness in turn could prove essential in preventing human factors-related aviation mishaps (Kang, 2008; Kang, Yuan, Liu , & Liu, 2008).

Multiple Resource Theory (MRT) by Wickens (1984, 2002, 2008) is a prominent theory of mental workload and aids in the prediction of success in multi-tasking. MRT is based on three major factors: 1) Resource Demand (task difficulty), 2) Resource Structure (neuropsychological characteristics of the individual brain), and 3) Dual Task Decrement (e.g. which task suffers when two are performed concurrently). In the area of neurophysiological / neurocognitive characteristics that may underlie MRT, more work needs to be done (Wickens, 2008). The research for this dissertation specifically investigated neurocognitive Resource Structure characteristics such as visual attentiveness, visual perceptiveness, and visual-spatial working memory as independent variables and the effects on pilot workload and situation awareness (Harbour et al., 2012; Kim, 2009; Endsley, 2012; Sulistyawati, Wicken, Chui & 2011; Vidulich & Tsang, 2012).

Current Independent View of the Multiple Resource Theory (MRT)

MRT has emerged as an important research topic in the past five years (Bulkley et al, 2009; Lei & Roetting, 2011; Pickel & Staller, 2012; Sarter, 2012; Vidulich & Tsang, 2012) and it is influencing the design of future information displays (Sarter, 2012). Multiple resource theory is posited as an alternative explanatory model to a single resource theory (Embrey, Blackett, Marsden, & Peachey, 2006). In the views of Sarter (2012) and Embrey et al. (2006), MRT is principally for modeling task difficulty (similarity level for multiple tasks) and human performance based on cognition utilizing groups of mental resources. MRT has shown to be effective in this area; empirical studies found r = 0.98 and an r = 0.92 in predicting hazard response time and in-vehicle task performance, respectively (Sarter, 2012; Vidulich & Tsang, 2012). At first, it was emphasized that MRT was intended to predict the outcome of one or two time-shared continuous tasks at an elementary level (Sarter, 2012). However, later in the field, neuroergonomic evidence has accumulated suggesting that both visual and auditory modes can mix to either limit and or enhance multimodal information processing (Sarter, 2012; Vidulich & Tsang, 2012).

MRT is evolving and feeding application models as tools for improving interface design (Sarter, 2012). As discussed by Lei and Roetting (2011), Wickens has made advancements to MRT both in 2002 and again in 2008. These advancements have expanded MRT while adding detail and granularity. Current MRT submits that there are limitations to attention resources as before. Among other changes, current evidence supports that two aspects of visual processing, referred to as ambient and focal (foveal) vision, appear to sometimes draw on separate resources, therefore tasks that draw on both aspects may result in relatively improved performance, while simultaneous tasks that load on only one aspect are likely to degrade performance when these processes occur simultaneously (Sarter, 2012). An important characteristic of this view of MRT is the proposal that the effect of task demand and resources may not be just qualitative but may also involve quantitative relationships (Embrey et al., 2006; Lei & Roetting, 2011; Padgett, 2004; Sarter, 2012; Vidulich & Tsang, 2012).

Recent Research Measuring Pilot Mental Workload

A recent study conducted by Harbour, Christensen, Estepp, and Gray (2012) was primarily application-based research to ensure that cardiac activity could indeed be taken in-flight and be reflective of pilot mental workload when looking at heart rate (HR) and HR variability (HRV). An exploration of the workload protocol and a preliminary assessment of pilot workload and situation awareness during flight was accomplished, as a trial study to improve the process and verify that it could be done using in flight heart rate recording. Initial comparisons were made between the Head Down Display (HDD), and the original Head Up Display (HUD) configuration while pilots performed various training maneuvers (Harbour et al., 2012).

This was a quasi-experimental study, with varying numbers of pilots represented in each comparison. Five-minute segments during each maneuver were analyzed by extracting the average HR and standard deviation of the R-R interval as a HRV measure (Harbour et al., 2012). It was noted that the psychophysiological measurement of HRV, which is objective, provided more granularity and significant differences in workload as a function of task and ID used than subjective surveys (Harbour et al., 2012). This work refined a neuroergonomic protocol for in-flight workload assessments and demonstrated that it is effective in this environment.

The addition of the objective physiological measurement of heart rate augments the veracity and robustness of the findings and provides a more complete picture of pilot workload and situation awareness (Harbour et al., 2012). Further research in this area needs to be accomplished, such as adding electroencephalogram (EEG) data collection, and testing for the effects of varying spatial locations of information displays (ID) (Harbour et al., 2012).

This completes the review of applicable research on mental workload; we will next turn to a model of attention that links Multiple Resource Theory to display usability, operator performance, and situation awareness (and the TMSA).

The Salience Effort Expectancy Value (SEEV) Model

A theoretical model of selective attention called the Salience Effort Expectancy Value (SEEV) model links basic research psychological models, salience and attention capture, engineering models, and expected value optimization (Wickens & McCarley, 2008). An example of SEEV's purpose could be to improve ID design in order to counteract inattention (Ma & Kaber, 2007; Matthews, Bryant, & Webb, 2001).

The SEEV is linked to MRT primarily through visual modality and it utilizes MRT in the creation of an attention based applications tool. More specifically, SEEV uses foveal vision as attention directly from MRT. The parameters of the SEEV (Wickens & McCarley, 2008), which drive visual attention around the environment, are: (1) Salience (S), the exogenous attention capturing properties of events, e.g. bright symbols that are salient on the ID, (2) Effort (Ef) that inhibits the movement of attention across longer distances, (3) Expectancy (Ex), the probability of seeing an event at a particular location, an endogenous cognitive factor that is calibrated by the individual to the frequency of events that occur at that location, and (4) Value (V), which is the importance (value) of tasks provided by the attended event, in addition to the relevance of the event to a valued task. Therefore, the Probability of Attending P(A) = s*S –ef*EF + (ex*EX + vV) or (ex*EX * vV). Wickens and McCarley (2008) found the SEEV model to have a correlation R-value of 0.78 for P(A) and actual attending, with a model fit (R)

>0.90. MRT is the fuel for the SEEV, and the SEEV is the filter application (Wickens & McCarthy, 2008).

With the application of the SEEV model, aircraft cockpits can be designed such that the location and appearance of symbology on the display more efficiently correspond with the actual environment in the most efficient prioritized manner. What the SEEV model lacked was the influence of individual ability on visual attention (individual as "Liveware"; Edwards, 1972), i.e. the levels of the individual's abilities in visual attentiveness, visual perceptiveness, and visual spatial working memory. Further individualization of SEEV would advance the theory by elucidating the effects of individual differences in visual abilities on resultant visual attention, which could conceivably result in individually customizable information displays that maximize usability improving SA, linking the SEEV and TMSA.

The SA and WL Relationship

Task difficulty has been demonstrated to influence mental workload, and mental workload in turn affects cognitive situation awareness (Svensson & Wilson, 2002). Substantial correlations have also been found between heart rate and mental workload, mental capacity, and cognitive situation awareness. Model analyses have shown a mental workload factor that contains both psychological and physiological properties, which in turn affects cognitive situation awareness (Svensson & Wilson, 2002). As mental workload goes up, cognitive situation awareness goes down. Consequently, as one measures the current psychological and physiological state of an individual, one is measuring mental workload and in turn, cognitive situation awareness (Gutzwiller & Clegg, 2012). This previous work did not, however, explore visual abilities as predictors of situation awareness or factors between mental workload and situation awareness (Kokar & Endsley, 2012; Svensson & Wilson, 2002). Predictive models of cognitive situation awareness within the flight deck context were lacking (Wickens, Sebok, Keller, Peters, Small, Hutchins, & Foyle, 2013).

Relating Visual Perception, Neuropsychology, and SA

The human eye allows one to detect and recognize objects that produce no odor, have no taste and feel, and make no sounds. Visual perception is a product of the entire visual system, which is composed of the eyes and several areas in the brain; these areas in the brain are vital for accurately processing visual information. The eyes serve as transducers that receive light energy and convert that energy into electric energy by means of neuronal processes - a transduction procedure (Blake & Sekuler, 2006). The world around us involves electromagnetic energy and light is in the optical spectrum of that electromagnetic energy. The visual system permits the human to utilize a portion of that electromagnetic energy contained in the visual spectrum by converting it into neural energy (Blake & Sekuler, 2006). This neural energy is processed by the brain so that the human can visually perceive what is out there in the world. Visual perception is both a biological and psychological process and seeing is a very dominant sense often overruling the other four senses. Visible light is electromagnetic radiation much like radio waves, microwaves, x-rays, gamma rays, or radar waves; together they make up the electromagnetic (EM) spectrum (Blake & Sekuler, 2006).

The method by which the nervous system converts stimuli into neural events is called sensory transduction and this involves neurons at the most fundamental level. The photoreceptors in the eye change the light energy entering the eye into electrical energy by way of neurons that generate neural signals (Blake & Sekuler, 2006). The pupil changes size to regulate how much light enters the eye and reaches the retina. All human eyes have a lens that assists in focusing the light (Blake & Sekuler, 2006). Near the center of the retina is where vision is the most acute, it is the center of the macula and termed the fovea (Blake & Sekuler, 2006). At the rear of the eye is the optic disk, made up of optic nerve fibers that leave the retina (Blake & Sekuler, 2006). Transmitted, translucent, and reflected light from objects enters the human eye through the pupil, it is then focused on the retina and there the photoreceptors biologically convert this information into electrical signals going from neuron to neuron by way of optic nerve fibers to the brain, which is where meaning is assigned to the image information.

In the retina the last stage of processing - determining lightness, sharpness, darkness, contrast, brightness, occurs in the neurons called retinal ganglion cells (Blake & Sekuler, 2006). The retinal ganglion cells have receptive fields that are composed of ON regions and OFF regions (Blake & Sekuler, 2006). Naturally ON regions respond to increases in light while OFF regions respond to decreases in light. A stimulus produces opposite effects in the center then the surrounding area of the ON and OFF regions and therefore the retinal ganglion cells function via an antagonistic process, and lateral inhibition is the interaction between these regions (Blake & Sekuler, 2006). The remaining neurons in the retina are composed of three types: Horizontal cells, Bipolar cells, and Amacrine cells (Blake & Sekuler, 2006). Horizontal cells logically connect photoreceptors laterally and they also modulate receptor signals (Blake & Sekuler, 2006). Bipolar cells receive input from photoreceptors, allowing them to react to light by changes in the levels of glutamate; more light causes decreased glutamate and decreases in light causes increases in glutamate, and therefore the bipolar cells produce graded signals corresponding to the levels of light (Blake & Sekuler, 2006). Amacrine cells modify responses of the bipolar cells acting as feedback and control cells (Blake & Sekuler, 2006). There are three types of retinal ganglion cells: Magnocellular (M cells), Parvocellular (P cells), and Koniocellular (K cells). M, P, and K cells differ in size, conductivity, and population, and allow the eye to produce signals for spatial resolution, temporal resolution, and contrast sensitivity, respectively (Blake & Sekuler, 2006).

Each optic nerve of the two eyes converges at the optic chiasm (Blake & Sekuler, 2006). Contralateral fibers cross to the opposite side of the brain while Ipsilateral fibers from each eye project to the same side of the brain (Blake & Sekuler, 2006). These optic tracts run from the chiasm to structures deeper into the brain (Blake & Sekuler, 2006), including the lateral geniculate and midbrain structures, though some fibers project directly to the cortex. Information from the optic tracts is thus transferred, directly and indirectly, to the primary visual cortex in the occipital lobe. Neural information from the primary visual cortex is distributed over a number of pathways to higher visual areas of the brain (Blake & Sekuler, 2006). Each and every cortical region receiving input from another region also sends feedback connections back to that other region creating duality of visual processing for parallel reliability and accuracy (Blake & Sekuler, 2006).

Visual processing is an important part of SA for flying an aircraft in that pilots scan the environment to include the IDs, monitoring the aircraft's location and response to his or her actions (Tirre & Gugerty, 1999, 2000). A component of performance in dynamic visual environments such as flying is temporal processing. For example, temporal processing is involved in estimating aircraft performance, based upon control inputs that are decided upon based on PFI presented on the ID. Visual processes that are necessary for self-motion (locomotion) also function to aid the pilot in landing an airplane. When a pilot flies the airplane on final approach, his or her vision is zeroing in on the runway, the focus is on the X intersection of the 1,000-foot makers, and the edges of the runway have an outward optic flow, if indeed the motion vector of the aircraft is centered on the runway (Gibson, 1986). A few seconds later, when the pilot is flying the airplane in the landing flare and is about to touch-down, they have to judge his or her time to contact (airplane's wheels time of impact with the runway). The human brain uses internal trigonometry and calculus to solve the Time of arrival = Distance / Rate problem (where the symbol '/' is divided by) (Blake & Sekuler, 2006; Stewart, Redlin, & Watson, 2007). The sight transduction process and intuitive brain calculation procedure allows the human visually to perceive motion in the world and maneuver within it.

Attention and Motion Perception

Targets are detected faster when their spatial location is cued in advance. This is why flight displays in cockpits are designed in a way with appropriate symbology that will cue the pilot to look in a certain direction to visually acquire the target faster, substantially decreasing target acquisition time. Ball and Sekuler (1981) performed experiments to see what affects attention levels would have on motion perception (Blake & Sekuler, 2006). The subjects were placed in front of a video screen to watch dots appear and move across the screen from various directions, and at different light levels or no dots would appear at all. Ball and Sekuler compared the intensity thresholds for subjects when they were not given any precursor cues for where and when the dots would appear, versus when the subjects were given cues. They found that when subjects were cued as to a subsequent dot their intensity thresholds for detection were lower than when they were not cued (Blake & Sekuler, 2006). The three top findings were: (1) If the orientation of the cue precisely matched the proceeding dot's direction of motion, the subjects had the lowest threshold; (2) if the orientation of the cue only simply approximated the proceeding dot's direction of motion, the subjects had a medium threshold; and (3) the cue was not helpful unless it preceded the dot by approximately 0.5 seconds, giving the selective attention process time to operate (Blake & Sekuler, 2006). Having the cue precisely match the proceeding dot's direction of motion in some ways illustrates the law of common fate, that is the human's propensity to group together individual elements that are moving in the same direction at the same speed. Potentially, that may be the best way to design the most effective cue.

Objective of the Display

The main purpose of the ID is to provide the pilot informational data for his or her SA by means of a pictorial display containing text and symbology. If the ID is difficult to see, confusing, misleading, or unclear, attention could be channelized on unimportant matters. These trivial matters could cause pilots to miss or skip vital checklist items pertaining to aircraft configuration, and lose current awareness of the aircraft's six degrees of freedom and or the location of other aircraft. This could ultimately lead to disastrous results.

Therefore, this research also examined relationships between the subject's inherent visual attention, visual-spatial working memory, and his or her respective level of WL and SA per given ID. In addition, the perceptual effects created by the ID on these cognitive phenomena as measured by the level of SA and mental WL was investigated.

Psychology based knowledge about the relationships between pilot neurocognitive factors and SA and WL will be significantly increased as will knowledge of the perceptions created as a function of ID design and those resulting variables (Bailey et al.,2011; Campbell, 2010; Campbell et al.,2010; Crawford and Neal, 2006; Flight Safety Foundation, 2009; Kim, 2009; Kramer, et al 2005; Wickens, 2008).

Display Design

The pilot does not have to switch attention back and forth between the HUD and the outside world when the the HUD is easily visible to the pilot while in a normal seating position and aligned with the outside view. Therefore, the HUD should enhance a pilot's ability to detect events in the external world as opposed to having to task switch between a traditional heads down (instrument panel) display and the external environment (Parasuraman and Rizzo, 2008).

The input process for SA formation is accomplished by way of information processing, which is critically dependent on attention (Crawford, 2006). Consequently, the pilot's inherent visual attention trait plays an important role in this process. Demonstrated by research, in general, humans are much better at detecting events in the environment if his or her attention is focused on the area in which those events occur (Wickens & Hollands, 2000). However, attention is a limited capacity resource. An ID design that encourages divided attention may inhibit the pilot's ability to focus attention on specific aspects of the ID (Verver s & Wickens, 1998). For example, if the pilot can only see a portion of the symbology on the HUD, they will then need to divide attention and cross check the HDD. For this reason, the HUD and the external world may not be processed or visually attended to at the same time as was intended. This results in a latency of information being processed because of the unattended domain being perceived only after some delay, therefore, change detection may be degraded (Crawford, 2006; McCann, Lynch, Foyle, & Johnston, 1993; Moodi, 1995). Perceptual aspects of the HUD visual field should be studied further (Crawford, 2006). The HUD should be designed to improve the ability of the pilot to concentrate attention robustly on the outside world (Crawford, 2006).

In a fixed-based simulator, an initial study comparing HUDs with HDDs found that landings were more accurate using HUDs (Crawford, 2006). High workload is associated with an increase in cognitive tunneling or focusing on one item or event causing other items of importance to be missed (Dowell, Foyle, Hooey, and Williams, 2002). It is believed that cognitive tunneling is caused by limitations in attentional capacity; therefore, increasing WL would further reduce a pilot's available capacity, in so doing worsening the tunneling effect (Crawford, 2006). However, there are very few studies comparing the workload of HUD and HDD (Crawford & Neal, 2006).

The work performed by Yamani and McCarley (2011), accomplished experiments to test whether design of symbology to produce visual search asymmetries could facilitate target detection in cluttered displays. Visual search asymmetry exists when, in two stimuli a target of one type is found efficiently among distractors of the second type, conversely a target of the second type would be found with difficulty among distractors of the first type. In this study, ten participants performed a visual search task using stimuli (canonical vs. reversed Ns) known to produce a search asymmetry. The search stimuli were either embedded within images containing either low or high levels of clutter. For statistical analysis, the values were submitted to a $2 \times 2 \times 5$ within-subject

ANOVA with clutter (high vs. low), target type (*N* vs. reversed *N*), and exposure duration (250, 750, 1,500, 2,500, and 5,000 ms) as factors. The background images with heavy clutter produced lower sensitivity than those with less clutter, $F_{(1, 9)} = 78.46$, $p < .01$, $MSE = .03$, η2 p = .90, and sensitivity was higher when the target was a reverse *N* among canonical *N* distractors than when the opposite target-distractor mapping was used, $F_{(1, 9)} = 104.89$, $p < .01$, $MSE = .003$, η2 p = .92, demonstrating the expected search asymmetry (Yamani & McCarley, 2011). Displays with heavy clutter required more processing time than less cluttered displays, $F_{(1, 9)} = 48.84$, $p < .01$, $MSE = 273165.28$, η2 p = .84, and mean processing time for the reverse-*N* targets was significantly shorter than for the canonical-*N* targets, $F_{(1, 9)} = 7.57$, $p = .02$, $MSE = 400181.01$, η2 p = .46, demonstrating a search asymmetry. Illustrating that heavy clutter did not reduce the strength of the *N*/reversed-*N* asymmetry in processing rates. The results showed that the search asymmetry was robust against the presence of heavy display clutter. Therefore, search asymmetries are robust against heavy, spatially continuous visual clutter, and this could be utilized to improve design of display symbology to maximize detectability of task-critical information in complex displays.

Cognitive Modeling

The study, Using Computational Cognitive Modeling to Diagnose Possible Sources of Aviation Error (Byrne & Kirlik, 2005), sought to expand knowledge in psychology in a way that allows the use of Artificial Intelligence (AI) to diagnose the causes of aviation error. This adds to theory in psychology in two ways: by finding the potential root causes of pilot error and by finding why and how the AI program is able, or not able, to model human behavior in order to discover the causes of this error. The study utilized the Adaptive Control of Thought–Rational (ACT-R) cognitive modeling/AI architecture. For the cognitive aspects in ACT-R, Subject Matter Experts (SME) were used to identify the pragmatic adaptations pilots bring to taxiing an aircraft (Byrne & Kirlik, 2005). Next, the SME information was placed into the ACT-R computational model. This model was closed-loop with the following links: pilot-aircraft-visual scene-taxiway. This system was created to potentially identify sources of taxi error.

The distinct contribution to the expansion of psychological knowledge was that the derived five decision strategies in an ACT-R model, ranging from cognitively demanding, but precise, to fast and careful, but robust, was accurate (Byrne & Kirlik, 2005). When the ACT-R model was compared by its behavior to a National Aeronautics and Space Administration (NASA) Ames Research Center simulation of Chicago O'Hare surface operations, the model selected the most accurate strategy even though the decision horizons were highly variable (Byrne & Kirlik, 2005). The contributions to theory were that a common thread in the simulation data revealed that errors occurred most frequently at atypical taxiway geometries or clearance routes, and the data provided empirical support for this ACT-R model (Byrne & Kirlik, 2005). In addition, the accurately predicted human behavior was due to being able to cope with short decision horizons by the use of globally robust heuristics in the ACT-R program (Byrne & Kirlik, 2005).

The NASA's Synthetic Vision Systems (SVS) project is focused on developing technologies that will replicate clear day flight operations, regardless of the actual outside visibility condition thereby eliminating low visibility conditions as a causal factor to aircraft accidents (Kramer, Prinzel, Arthur, & Bailey, 2004). This study expanded psychological knowledge by assessing the effect of different guidance concepts upon pilot Situation Awareness (SA), mental Work Load (WL), and aircraft flight path tracking performance for an SVS system using a Head-Up Display (HUD) (Kramer et al., 2004).

Specifically, two central guidance concepts were assessed using tunnel formats: dynamic or minimal, and they were also assessed against the baseline condition (no tunnel) (Kramer et al., 2004). This was accomplished in a flight simulator with simulated Instrument Meteorological Conditions (IMC) flying approaches to Reno-Tahoe International airport (Kramer et al., 2004). Two main guidance cues, tadpole and follow-me aircraft, were also evaluated in the both the dynamic and minimal guidance domains to assess their effect with tunnel formats (Kramer et al., 2004).

The particular psychology knowledge gained was that the presence of a tunnel on an SVS HUD had no effect on flight path performance. However, it did have significant effects on pilot SA and WL (Kramer et al., 2004). The psychology theory that was gained by this study is that the relationships among the variables of different SVS HUD guidance concepts and SA and WL is that the dynamic tunnel concept with the follow-me aircraft guidance symbol created the lowest workload for the pilot while providing the highest level of SA among the concepts assessed (Kramer et al., 2004).

For the next study using a densely populated battlefield Current Operational Picture (COP), different icon modalities were assessed to evaluate the effects on operator Situation Awareness (SA) (Strater, Riley, Faulkner, Hyatt, & Endsley, 2006). For a baseline, military standard battle field symbology was compared to various modified versions of this symbology. The Situation Awareness Global Assessment Technique

(SAGAT) was the instrument utilized to extract SA data after each exercise using the different symbology. Subjects also indicated their perceived utility of the icon being assessed in terms of supporting SA as part of data collection.

The study's contribution to increasing psychology knowledge is that, as showed by the objective SAGAT results, subject SA performance was greatest using the proportional icon modality (Strater et al., 2006). It should be noted that the subjects' perception which was strongly influenced based upon what they were the most familiar with, was that the current military standard representations are easiest for assisting them in monitoring friendly and enemy forces. However, as indicated above, the objective SAGAT measure showed different (Strater et al., 2006) results. The study's contribution to psychology theory was twofold: 1) it illustrated the relationship between the variables of icon modalities and SA and 2) the findings also verified that a relatively minor design difference in icon pattern can have a significant impact on operator SA (Strater et al., 2006). Increasing SA increases the available cognitive capacity that can be directed toward other tasks (Strater et al., 2006). It also showed once again how objective and subjective measurement could diverge.

Summary

Situation awareness, as codified in the TMSA and applied to the task of piloting an aircraft, is built upon fundamental cognitive abilities. These include visual attention, as detailed in the SEEV model, and spatial working memory, as discussed in Baddeley's work. Mental workload is a critical construct, as overloading the resources identified in the MRT will cause a considerable degradation of situation awareness. There was no consensus on predictors for situation awareness, and this area tended to be elusive. None of the extant work had thus far successfully explored the individual differences in visual abilities that are critical to forming and maintaining SA (Douglas, Aleva, & Havig, 2007; Ellis & Levy, 2009; Elliott et al., 2009; Endsley, 2012; Gillan et al., 2009; Gugerty, in press; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Jodlowski, 2009; Lau, Jamieson, & Skranning, 2013; Proctor & Vu, 2010; Sulistyawati, Wickens, & Chui, 2011; Vidulich & Tsang, 2012; Wickens, 2008; Wickens & McCarley, 2008; Tirre & Gugerty, 1999, 2000) and consequently this dissertation is the logical next step in that scientific endeavor, through inquiry and discovery, towards theory in psychology. This study will improve the TMSA by finding the relationships between inherent neurocognitive factors and changes in situation awareness and workload, a critical, substantial, and significant gap in the TMSA.

These relationships were explored by varying task difficulty, induced via manipulation of the ID spatial location and usability. This research dissertation sought to maximize ecological validity by conducting data collection during actual flight, and maximized the knowledge gained through the application of neuroergonomic techniques. Irrespective of the scientific necessity, there was no firm grounding for current theories of situation awareness in fundamental cognitive and perceptual processes as links and predictors. Since Endsley's Theoretical Model of Situation Awareness (TMSA, 1995a) was first published, models of situation awareness were still conceptual models that provided little specificity with regards to the neurocognitive processes that are necessary for the formation and maintenance of situation awareness (Gillan et al., 2009; Lau, Jamieson, & Skranning, 2013; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). While the TMSA recognized perception as a critical first step, there were no specific or quantitative links between perceptual abilities and situation awareness; nor had subsequent work been able to clarify the issue, e.g. the effects of visual ability on the level of situation awareness (Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Vidulich & Tsang, 2012; Sulistyawati, Wickens, & Chui, 2011). Needed theoretical advancement in this area continued to be hampered by a lack of specific, testable predictions regarding plausible component processes; there had been little theoretical progress due to this (Douglas, Aleva, & Havig, 2007; Endsley, 2012; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens, 2008; Sulistyawati, Wickens, & Chui, 2011).

The seminal research done by Tirre and Gugerty (1999, 2000), Wickens and McCarley (2008), Elliott et al., (2009), Jen-li, et al., (2013), and Gugerty, (in press) found that visual processing (Proctor & Vu, 2010) was involved in situation awareness (Vidulich & Tsang, 2012). However, the specific component processes were yet to be explored in detail (Gutzwiller & Clegg, 2012; Gugerty, in press; Harbour et al., 2012; Jen-li et al., 2013; Jones & Endsley, 2012; Sulistyawati et al., 2011; Vidulich & Tsang, 2012). Visual processing can be categorized as static and dynamic (Proctor & Vu, 2010).

As situation awareness develops, in the same way, as discourse comprehension, event-base development begins through a strictly bottom-up process driven by sensory information. Therefore, for Level 1 in situation awareness (perception) to occur correctly it is vital to the initial stage of visual perception and the processing of that information to also occur properly. Top-down processing is utilized to allow assigning the appropriate meaning in a particular context to the visual information, which requires WM, specifically visual-spatial WM (Durso et al., 2007; Matlin, 2008) for spatial information.

This would entail three variables: visual perceptiveness, visual attentiveness, and visual-spatial working memory (WM) (Blake & Sekuler, 2006; Brain Train, 2010; Matlin, 2008; Carlson, 2010). These may be summarized as: a) did the pilot see it at all, b) did the pilot attend to it, and c) did the pilot encode it in memory such that he or she could use it in building a situation model. An understanding of visual processing factors (such as independent variable/s) operating in dynamic environments was incomplete (Crawford & Neal, 2006; Elliott et al., 2009; Tirre & Gugerty, 1999; Wickens, 2002). This suggested that the inherent neurocognitive factors of visual attention (perceptiveness and attentiveness) and visual-spatial working memory, as part of a theory may explain their support for the development of situation awareness. Consequently, these may be operationalized as visual attentiveness and perceptiveness, integrated with visuospatial memory (Brain Train, 2010; Christensen et al., 2013; Corbett & Constantine, 2007; Endsley, 2012; Gugerty, in press; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994; Vidulich & Tsang, 2012; Wickens & McCarley, 2008).

Therefore, visual attention (perceptiveness and attentiveness) and visual-spatial working memory and processing were treated as independent variables in order to better develop a definitive psychological model and theory for situation awareness prediction and understanding, known as the *Enhanced-TMSA*. The current study, therefore, tested explicit hypotheses regarding specific abilities that contribute to situation awareness; the results of which fill in a critical gap in the TMSA, and in so doing enable both theoretical refinement (providing an *Enhanced-Theoretical Model of SA*) and practical applications such as improved procedures, training for pilots, and display design that improve flight safety.

Chapter 3: Research Method

Introduction

The experimental study of situation awareness presents particular challenges. Situation awareness is highly context-specific; experimental testing and manipulation must be conducted with respect to an actual task. As previously discussed, it is a complicated tangible that is not well addressed by laboratory study focusing on simple, artificial tasks. Consequently, the use of a meaningful, consequential task context is essential to the study of situation awareness. This chapter will review the problem and purpose of the study, and then link the study's hypotheses to the experimental design with a real-world task that tested those hypotheses.

Despite the scientific necessity, there was no firm grounding for current theories of situation awareness in fundamental cognitive and perceptual processes still. In the face of nearly 20 years of work since Endsley's Theoretical Model of Situation Awareness (TMSA, 1995a) was first published, current models of situation awareness were yet conceptual models that provided little specificity with regards to the neurocognitive processes that are necessary for the formation and maintenance of situation awareness (Gillan et al., 2009; Lau, Jamieson, & Skranning, 2013; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). While the TMSA recognized perception as a critical first step, there were no specific or quantitative links between perceptual abilities and situation awareness; nor has repeated subsequent work been able to elucidate the issue (Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Vidulich & Tsang, 2012; Sulistyawati, Wickens, & Chui, 2011). Needed theoretical advancement in this area continued to be hampered by a lack of specific, testable predictions regarding plausible component processes; there had been little theoretical progress because of this (Douglas, Aleva, & Havig, 2007; Endsley, 2012; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens, 2008; Sulistyawati, Wickens, & Chui, 2011).

The seminal research done by Tirre and Gugerty (1999, 2000), Wickens and McCarley (2008), Elliott et al., (2009), Jen-li, et al., (2013), and Gugerty (in press) found that visual processing (Proctor & Vu, 2010) was involved in situation awareness (Vidulich & Tsang, 2012). However, the specific component processes were not yet explored in detail (Gutzwiller & Clegg, 2012; Gugerty, in press; Harbour et al., 2012; Jen-li et al., 2013; Jones & Endsley, 2012; Sulistyawati et al., 2011; Vidulich & Tsang, 2012). Therefore this work tested explicit hypotheses regarding specific abilities that contribute to situation awareness; the results of this study fills in a critical gap in the TMSA, and in so doing enables both theoretical refinement and practical applications such as improved procedures, training for pilots, and display design that improve flight safety.

Visual processing can be categorized as static and dynamic (Proctor & Vu, 2010), and may be operationalized as visual attentiveness and perceptiveness, integrated with visuospatial memory (Brain Train, 2010; Christensen et al., 2013; Corbett & Constantine, 2007; Endsley, 2012; Gugerty, in press; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). Consequently, the primary purpose of this quasi-experimental quantitative study was to test the predictive value of these specific candidate visuo-cognitive abilities as predictors of situation awareness. Therefore, this project tested the predictive value of these variables as factors between a particular task to be performed and the eventual outcome of situation awareness. As Pavlov, Watson, and Skinner performed field experiments in order to contribute to psychological theory (Cervone & Pervin, 2007), a field experiment in the paradigm of neuroergonomics (Parasuraman, Christensen, & Grafton, 2012) employing quasi-experimental repeated-measures (within-participants), was used for this study.

This was the most effective and realistic method to perform the research that addressed the problem and the purpose. As computed by G*power, this study required a sample size of a minimum of 12 United States Air Force (USAF) pilots. These pilots were recruited at an airport in north central Ohio by utilizing a recruitment memo in squadron buildings. All participants were pilots qualified in the aircraft. There were two display conditions that varied the difficulty of maintaining SA by varying the presence and position of the information display. The first condition had an Information Display (ID) design that was near optimal and centered on the pilot's field of view and was no more than five degrees above or below the pilot's line of sight (Harbour, Hudson, & Zehner, 2012). The second condition had an ID design that was suboptimal and well out of pilot line-of-sight (a 35 degree vertical drop) (Harbour, Hudson, & Zehner, 2012). This display manipulation induced variation in task difficulty, to observe differential effects on both subjective and psychophysiological measures (see Figure 3). This work was successful and will result in significant elaboration of theoretical models of situation awareness as well as enabling and focusing efforts to improve situation awareness. The bottom line is what were the effects of visual ability on the level of situation awareness? To address the research questions, the following hypotheses were tested:

Q1. Under varying task difficulty, are there statistically significant effects of subject inherent visual attentiveness on situation awareness?

Q2. Under varying task difficulty, are there statistically significant effects of subject inherent visual perceptiveness on situation awareness?

Q3. Under varying task difficulty, are there statistically significant effects of subject inherent visual spatial working memory on situation awareness?

Hypotheses

To address the research questions, the following hypotheses were tested:

H1$_0$. Under varying task difficulty, there was no statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H1$_a$. Under varying task difficulty, there was statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H2$_0$. Under varying task difficulty, there was no statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H2$_a$. Under varying task difficulty, there was statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and

Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

$H3_0$. Under varying task difficulty, there was no statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

$H3_a$. Under varying task difficulty, there was statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

Research Methods and Design

The primary purpose of this quasi-experimental quantitative study was to test visual perceptiveness, attentiveness, and spatial working memory as predictors of situation awareness. In order to maximize ecological validity and minimize nuisance variance due to heterogeneous participants, this project focused on the controlled assessment of the visuocognitive abilities of Air National Guard pilots, with actual piloting as a completely real task suitable for measuring resulting situation awareness.

This was the most effective and realistic method to perform the research that addresses the problem and the purpose. As an example alternative approach, a wholly laboratory based study utilizing the typical convenience sample of college undergraduates could have been accomplished; however, one would expect substantial individual differences as well as serious concerns about the measurement of situation awareness outside any meaningful task context.

In order to induce meaningful variation in the outcome measures of situation awareness, task difficulty in the flight task was manipulated between two levels: a *low* *difficulty level* associated with effective and easy-to-use information displays and a *high difficulty level* associated with ineffective information displays. Each pilot was assessed for the three candidate visual abilities (attentiveness, perceptiveness, and visuospatial working memory). This approach resulted in a quasi-experimental design that made use of repeated measures comparisons (Cozby, 2001; see Table 3) four times per subject, in order to achieve required statistical power.

The experiment was organized in much the same manner as a strict experimental design, however, due to the operational realism involved, it lacked complete randomness (Creswell, 2009; de Vaus, 2001; Moore, 2007). This lack of randomness was recognized and was accounted for during the entire experimental process (Trochim & Donnelly, 2008). This tradeoff between experimental control and ecological validity, while a compromise, improved the validity, generalizability, and significance of this study (Alasuutari, Bickman, & Brannen, 2008).

Correlation and causation analysis utilizes mathematical tools such as the within-subjects and factors repeated-measures Analysis of Variance (ANOVA) and linear multiple regression modeling to study effects on one dependent variable by more than one independent variable (Grim & Yarnold, 2006). The factorial Analysis of Variance (ANOVA) begins with the premise of the foundation of multivariate statistics in providing a simultaneous analysis of multiple independent variables and the dependent variable (Grim & Yarnold, 2006).

Table 3

The 2 X 3 Matrix

		Visual Abilities (IVs)		
		V_a	V_p	V_{swm}
Display Condition (Task Difficulty)	HUD	SA	SA	SA
	HDD	SA	SA	SA

Table 3 illustrates that task difficulty was varied by display use manipulation (a controlled covariate variable) so the effects of visual abilities (V_a, V_p, and V_{swm}) on the level of SA could be more realistically studied.

Multiple ANOVAs would be required to test for each independent variable; therefore, the factorial ANOVA is preferred; this is an ANOVA with several independent variables (Grim & Yarnold, 2006). The factorial ANOVA has advantages over the ANOVA. There is an increased chance of discovering which factor is most important, by measuring several independent variables in the same experiment (Tabachnick, & Fidell, 1996). Differences in variables can be more salient utilizing the factorial ANOVA versus using several ANOVAs. The factorial ANOVA also allows for better control of statistical error in significance testing. There are two kinds of errors that can be made in significance testing: type I and type II. Type I is considered to be the most serious and it is when a true null hypothesis is incorrectly rejected. Type I error can occur if multiple ANOVA's are conducted independently, whereas using a single factorial ANOVA instead could reduce the likelihood of Type I error (Green & Salkind, 2008; Grim & Yarnold, 2006; Tabachnick, & Fidell, 1996).

This ANOVA type has the ability to illustrate the effects of the input (independent variables) on the output (dependent variable) of the system in the experiment, while reducing the likelihood of type I error. The within-subjects and factors repeated-measures ANOVA was used to measure the main effects of the independent variables (task difficulty and three visual abilities) the interactions among the independent variables, the importance of the dependent variable (situation awareness), and the strength of association between these variables.

This experiment/research was a within-subject design. In between-subject designs, the differences among participants are uncontrolled and are treated as error (Jackson, 2009; Shavelson, 1996). In within-subject designs, the same participants are tested in each condition, with repeated sampling of each condition. Therefore, differences among participants can be measured and separated from error (Jackson, 2009; Shavelson, 1996). Removing variance due to differences between participants from the error variance substantially increases the power of significance tests (Grim & Yarnold, 2006). Therefore, within-participants designs are almost always more powerful than between-subject designs. Since power is such an important consideration in the design of experiments, within-subject designs are generally preferable to between-subject designs (Jackson, 2009; Shavelson, 1996).

Population

For this study, the population was Ohio Air National Guard pilots (part of the U.S. Air Force), which are a relatively homogeneous group; the Air Force in a rigorous process selects these individuals, and all have completed highly regimented initial and recurrent training. Consequently, this homogenous, expert population of 26 (USAF, 2013) are more likely to show consistent effects of both task difficulty and visual abilities. The differences are and were in the pilots' level of neurocognitive ability, because while visual acuity is carefully controlled, the USAF currently has no established requirements or tests for the neurocognitive visual abilities (Butcher, 2007).

Sample

Participants were recruited from the National Guard, by circulating memos throughout the base. This targeted sampling is necessary, as the study requires a relatively homogenous, expert population from both a real world and scientific standpoint. On the practical side, participants must be qualified and experienced Ohio Air National Guard pilots in order to fly the aircraft. From a scientific perspective, this relatively homogenous participant pool helps ensure that observed differences are traceable to the study manipulations, and do not reflect error differences. This does have the consequence of reducing the ability to generalize to non-studied populations, but the tradeoff was felt acceptable in light of the many other benefits of the study design, including high ecological validity and significantly reduced complexity and cost in the conduct of data collection. All participants were qualified pilots in the aircraft that was used for the study. There were no restrictions as to geographical location or ethnicity (however, individuals who reside far from Ohio were very unlikely to participate). The instruments were offered in English only, and sufficient comprehension of the English language was assumed. Purposive sampling as for this study can be very helpful when the researcher needs to reach a targeted sample in a reasonable amount of time and where sampling for proportionality is not the primary concern (Jackson, 2009; Moore, 2007). Using purposive sampling, the researcher is likely to get the answers from the target population, but this also increases the risk of getting overweight in subgroups in the population that are more readily accessible (Jackson, 2009).

In keeping with basic human subjects' research protections, this study relied on volunteers from the population, with the total number goal at the minimum necessary to accomplish study goals based on *a priori* power analysis. The first step in the sample size calculation for this type of study is determining or estimating the effect size. The effect size is the potency of the intervention or the strength of the relationship under investigation (Cohen, 1992). By calculating an effect size as part of the analysis of the data it can assist in determining if the research has found something meaningful (not merely statistically significant). Therefore, in advance of doing the study one must estimate the effect size in the study (NCU, 2011). Lipsey and Hurley (2009) describe a way to estimate effect size by reviewing the literature on the same or similar relationships or interventions to find the range of relevant effect sizes to estimate the effect size for one's study.

In the literature, usability problems or excelling attributes with varying display designs (the varying of task difficulty) are likely to be detected with an effect size of approximately 0.4 (Jacko, 2012; Lewis, 1994, 2001, 2006; Nielsen, Jakob, & Landauer, 1993; Nielsen, 2000, 2004; Sauro & Lewis, 2005; Virzi, 1990; Smith, 2001). Caulton (2001) indicated that a modest effect estimate such as this should only be used if given a firm homogeneity assumption – that is the types of participants being sampled will have the same probability of encountering usability issues based on the characteristics of the participants and therefore the resultants were influenced by that modest effect estimate. The assumption of homogeneity is reasonable given the population of selected Ohio ANG pilots flying the same type aircraft; consequently, the moderate effect size of 0.4 is appropriate for power analysis.

By convention, studies in human factors psychological research that are similar in nature to this study, i.e. performed in aeronautics with actual pilots in a simulator or actual flight, use no more than 8 to 12 participants (AFFSA, 2007; Gallimore & Liggett, 2001; Liggett & Gallimore, 2001, 2002, 2003). Rather than relying solely on this conventional wisdom, for this research G*Power 3.19 was used to conduct *a priori* power analysis. The appropriate statistical test chosen was the ANOVA: Repeated measures, within factors. The same pilots flew using the two different display designs in order to vary task difficulty, and exhibited a range of the three visual abilities (perceptiveness, attentiveness, and spatial memory) resulting in a 2 (displays) x 3 (visual abilities) design, and (2x3) six cells (termed groups in G*Power) total. This study was searching for any significant effects by these independent variables on the dependent measures of situation awareness. The estimated Effect Size is moderate at 0.40 which is the effect size measure indicating the total variance explained by the independent variables and interactions. Each condition should be and was repeated a minimum of four times.

A priori, computed sample size required for a given power, alpha, and effect size was calculated, using the ANOVA: Repeated measures, within factors with a moderate effect size of 0.40, the power was set to a minimum to the desired level post hoc of 0.8 and the alpha error probability was set to 0.05 (for one tail) yielding a minimum sample size of 12 participants and a critical F of 3.1599. This suggests that approximately 12 participants should result in an adequately powered study (see Table 4 *A Priori Computed Required Sample Size*).

Table 4

A Priori Computed Required Sample Size

	F tests - Factorial ANOVA: Repeated measures, within factors	
	Analysis: *A priori*: Computed Required Sample Size	
Input:	Effect size f	0.4
	α err prob	0.05
	Power (1-β err prob)	0.8
	Number of Groups	6
	Number of Measurements	4
	Corr among rep measures	0.75
	Noncentrality parameter λ	30.72
Output:	Critical F	3.16
	Numerator df	3.00
	Denominator df	18.0
	Total Sample Size	12
	Actual Power	0.99

Table 4 shows the results of *a priori* power analysis from G*power, power = 0.99.

Demographic information was gathered for each participant: year of birth, crew position, number of years of flight experience, total number of flight hours, gender, education, and flying hours in aircraft being studied. Participant age was calculated as year of birth subtracted from 2014.

Materials/Instruments

The chosen procedures, instruments, and measurements are described under *Operational Definitions of Variables.* They were minimally intrusive, and the instruments that were used have been well-established in previous research (Harbour et al., 2013). The data was collected in actual flight operations to maximize the ecological validity of this study (Harbour et al., 2013). In order to provide robust measurements of situation awareness and workload to support the correlational analyses, multiple subjective and psychophysiological measures were taken from each participant. This enabled a holistic approach (Hankins & Wilson, 1998).

Participants were given a computerized test for inherent visual attention, as the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010; Sandford & Turner, 1994, 1995) and they were given a test for Visuospatial Working Memory (Spreen & Strauss, 2006). Both tests were presented on a laptop PC with 17" display with an external mouse and built-in keyboard for input and a headset. For the IVA+, the validity of a participant's scores was checked independently for auditory and visual modalities, therefore, utilizing only the visual modality portion was valid. The IVA+ is a 13 to 15 minute test that is comprised of 500 trials, normalized from 5 – 90 years of age, has demonstrated concurrent validity (>90%) with other instruments, is malingering proofed, and exhibits no substantial practice or learning effects (Anatasi & Urbina, 1997; Brain Train, 2010; Sanford & Turner, 1994, 2001). For the IVA, as similarly employed by commonly used IQ tests, all quotient scores are normalized and have a mean score of 100 and a Standard Deviation (SD) of 15. By this definition, approximately 68 percent of the general population scores between 85 and

115, which is within one standard deviation of the mean. The IVA is a ratio level of measurement with a true zero and a maximum of 200. This applies to both V_a and V_p.

The Visuospatial Working Memory test (spatial n-back) is a two-back forced choice computerized test paradigm in which the participant is presented with a black X, which can appear at any of five different locations on the screen (AFRL, 2009; Gevins & Cutillo, 1993; Sohn & Doane, 1997, 2000, 2003). Participants observe a sequence of presentations of the X at the different locations; their task is to compare the current position of the X to where the X appeared two presentations prior. This is done on a continuous basis, requiring the participants to hold the two previous presentation locations in spatial working memory. This test is repeated multiple times, over five minutes. The spatial n-back task is a test of the participant's ability to retain spatial information and to manipulate remembered items in working memory (AFRL, 2009; Sohn, & Doane, 1997, 2000, 2003). It is reliable across people and studies (Owen, McMillan, Laird, & Bullmore, 2005); see Table 5.

The Ttesting also consisted of standard subjective inventories delivered as pencil and paper instruments (Bedford Workload Scale, Roscoe, & Ellis, 1990; China Lake Situation Awareness Scale, Adams, Kane, & Bates, 1998), and objective psychophysiological measures such electrocardiographic analysis of heart rate (HR) and heart rate variability (HRV) during flight (Hankins & Wilson, 1998; Nickel & Nachreiner, 2003), and the electroencephalogram (EEG) analysis of theta and alpha brainwaves in-flight (Wilson, Estepp, & Davis, 2009; see Table 5). The Bedford Workload scale is appropriate for in-flight evaluations, additionally it is sensitive and reliable (Handbook of Flight Deck Research, 1995). This survey/questionnaire is based on a binary decision tree structure. The participants are asked to self-assess whether: (1) it was possible to complete the task, (2) the workload was tolerable, and or (3) the workload was satisfactory without reduction. The rating-scale end points are '1 - workload insignificant' to '10 - task abandoned. For this study, the Bedford definition of workload focused on the mental effort required to satisfy the perceived demands of a specified task. Spare capacity was used to define levels of workload. The Bedford has demonstrated its value in several trials and for the purpose of the research it was apropos that it have an interval level of measurement (Roscoe & Ellis, 1990; Handbook of Flight Deck Research, 1995).

The Situation Awareness rating scale known as the China Lake Situational Awareness (CLSA) can be used for in-flight or post-flight data collection (Roscoe & Ellis, 1990; Handbook of Flight Deck Research, 1995). The CLSA is administered similar to the Bedford Workload Scale; it has a unidimensional rating scale and a clearly defined set of criteria for ratings. The CLSA has high face validity, is easily understood and straightforward to administer (Handbook of Flight Deck Research, 1995) and is based on the Bedford WL scale. Confidence has been well established for the validity and reliability of the CLSA, and the scale has been duly normed against the USAF pilot subject population (Roscoe & Ellis, 1990; Handbook of Flight Deck Research, 1995). For the purpose of the research it was apropos that, the CLSA use an interval rating scale with five possibilities: 1 being Very-Good and 5 being Very-Poor. Each point on the five-point scale refers to a description of the SA experienced (CLSA; Adams, Kane & Bates, 1998). See Table 5.

The Bedford Workload Scale and China Lake Situation Awareness Scale were administered to the pilots post-flight, in order to avoid interference with piloting tasks. During flight, heart rate was measured with the use of three-lead ECG (Hankins & Wilson, 1998; Nickel & Nachreiner, 2003). The objective measures obtained from ECG included heart rate (HR) and heart rate variability (HRV). Both measures have been extensively studied. The electrocardiographic data was collected using a Vitaport system (Temec Instruments B.V., Kerkrade, Netherlands), which is a small, portable pilot-worn physiological data collection system with onboard digital data storage. The three leads were placed on left and right clavicles and sternum; impedances were verified at or below 40 kilo-ohms. After completing written informed consent, participants were instrumented for the ECG. The researcher observed pilot activities onboard from the jump seat and use dedicated marker channels along with written notes to time stamp and categorize flight segments and events of interest. The HR and HRV data was analyzed by extracting 5-minute segments during each maneuver. ECG data was band-pass filtered from .4 Hz to 30 Hz. R wave peaks were marked using QRS tool based on threshold detection followed up with visual inspection and correction. Inter-beat intervals were exported for subsequent analyses of average HR and SDNN (in this case, standard deviation of the R-R interval) by way of Fourier Transform analysis using MATLAB.

Psychophysiology measurements for EEG and ECG have demonstrated 83.4 to 85% accuracy in measuring mental workload (Wilson & Russell, 2003; Wilson, et. al, 2009). The heart's rhythmic activity to include heart rate (HR) is influenced by higher-order brain centers (Wilson, 2002). Cognitive activity will change the rhythmic patterns of the heart, which is heart rate variability (HRV); therefore, as cognitive activity occurs, such as mental workload, it causes a change in HRV (Wilson, 2002). Increased mental workload will lead to an increase in sympathetic nervous system activity, and a decrease in parasympathetic nervous system activity for heart beat regulation (Wilson, 2002). Consequently, HR increases as mental WL increases and HRV decreases as WL increases (Wilson, 2002).

Electroencephalography (EEG), as a psychophysiological measure, has been successfully used to estimate an operator's cognitive state (Wilson, 2002). Topographic EEG data has shown changes in the scalp-recorded patterns of alpha activity that are consistent with the mental demands of the various segments of the tasks being performed (Wilson, in press). Spontaneous EEG has been conventionally classified into five clinical frequency bands, derived via Fourier transform of time-series EEG data: delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-31 Hz), and gamma (31-43 Hz) (Wilson, 2002). To determine a person's cognitive state for use in applications such as workload assessment and adaptive automation, the spontaneous EEG has been widely used, even without specific events from which event related activity could be obtained (Wilson, 2002).

Operational Definition of Variables

The independent variables for this study were the pilot neurocognitive factors visual attentiveness (V_a), visual perceptiveness (V_p), and visuospatial working memory (V_{swm}) (Task difficulty was manipulated by varying which display is used: HDD or HUD, and was a controlled covariate variable but was not a specific independent variable). The dependent variable was both an objective and subjective measure of situation awareness.

The three different IVs (V_a, V_p, V_{swm}) were logically categorized (categorical level variables) for the Factorial ANOVA. They were categorized as Low, Medium, and High, and placed into 3 bins as a function of Z-score (Low < -1, $-1 \leq$ Medium $\leq +1$, $+1 <$ High) for three groups for a total of 12 subjects (repeated measures within subjects). This binning process renders the IV categorical and is a relatively common way to reduce nuisance error in the measurements. Additionally, the Scheffe Post Hoc tests were run. However, for the (Pearson) correlation, and multiple regression modeling, these three IVs were treated as a ratio level of measurement (ratio level variables) per the IVA+. The following are operational explanations of the independent variables, dependent variable, and covariates used for the study (see Table 5).

Table 5

Variable Operation and Level

Independent Variables		Dependent Variables	
Operation	Level	Operation	Level
Attentiveness (V_a)$^{\lambda}$ Visual Ability	Ratio $^{\lambda}$: (Normalized 0 - 200)	China Lake (SA)	Interval: 1 - Very Good to 5 - Very Poor
Perceptiveness (V_p) $^{\lambda}$ Visual Ability	Ratio $^{\lambda}$: (Normalized 0 - 200)	Bedford (SA)*	Interval: 1 - Workload Insignificant to 10 - Task Abandoned, Pilot unable to apply sufficient effort.
Spatial Working Memory (V_{swm}) $^{\lambda}$ Visual Ability	Ratio $^{\lambda}$: (0 - 100% Correct)		
		ECG (WL)*^	Ratio (0 to 200): Heart Rate (bpm) Heart Rate Variability (ms)
		EEG (WL)*^	Ratio (0 to 200μV): Brain Wave Frequency Band Amplitude

*Work Load can be an implicit measure of Situation Awareness (SA) (Gutzwiller & Clegg, 2012). Task manipulation was accomplished by utilizing HUD vs. HDD, but was not counted as an IV. Task difficulty was varied by display use manipulation (a controlled covariate variable) so the effects of visual abilities (V_a, V_p, and V_{swm}) on the level of SA could be more realistically studied.

^Composite SA score between the two surveys was verified by corresponding HR, HRV, and EEG objective data. Observation notes were taken of pilot performance as well.

$^{\lambda}$ The 3 different IVs (V_a, V_p, V_{swm}) were logically categorized (categorical level variables) for the Factorial ANOVA repeated measures within subjects. They were binned into Low, Medium, and High, and placed into 3 bins of subjects per group for a total of 12 subjects (repeated measure within subjects). This binning process renders the IV categorical and is a relatively common way to reduce nuisance error in the measurements. They were categorized as Low, Medium, and High, and placed into 3 bins as a function of Z-score (Low < -1, -1 ≤ Medium ≤ +1, + 1 < High) for 3 groups for a total of 12 subjects (repeated measures within subjects). Additionally, the Scheffe Post Hoc tests were run. However, for completeness the (Pearson) correlation, and linear multiple regression modeling these 3 IVs were indeed treated as a Ratio Level of measurement (ratio level variables) per the IVA+.

Table 5 illustrates the independent and dependent variables along with their operation and level.

Display Used (Controlled Covariate Variable). This was the quality of the display design and was varied to induce changes in task difficulty. There were two levels that were used for this study: HUD and or HDD. In essence, these levels vary the spatial separation between a pilot's display and his or her normal out the window gaze (see Figures 3, 4, and 5). The level of measurement was nominal and the FARO arm (Harbour & Hudson, 2012) in 3-dimensional space measured spatial separation with the units of millimeters and degrees in order to sort this into two categories. The HUD is near optimal and centered on the pilot's FOV plus or minus 5 degrees; it was expected to be psychologically non-refractory (Harbour, Hudson, & Zehner, 2012). The Head Down Display (HDD) has an ID design that is suboptimal and well out of pilot line-of-sight (a 35 degree vertical drop) (Harbour, Hudson, & Zehner, 2012). This design was expected to induce psychological refractory periods (PRPs, Proctor & Vu, 2010) due to the need to switch between the HDD and the upper view of the outside world. This large drop was expected to produce correspondingly more frequent PRPs. Consequently, the variation in the spatial spread of information displays in the cockpit was expected to induce variation in task difficulty, in order to observe differential effects on subjective and psychophysiological measures. This task difficulty was varied by display use manipulation (a controlled covariate variable) so the effects of visual abilities (V_a, V_p, and V_{swm}) on the level of SA could be more realistically studied. This was coded by HDD = High Task Difficulty = 2, and HUD = Low Task Difficulty = 1. (see Figures 3, 4, and 5, and Table 5).

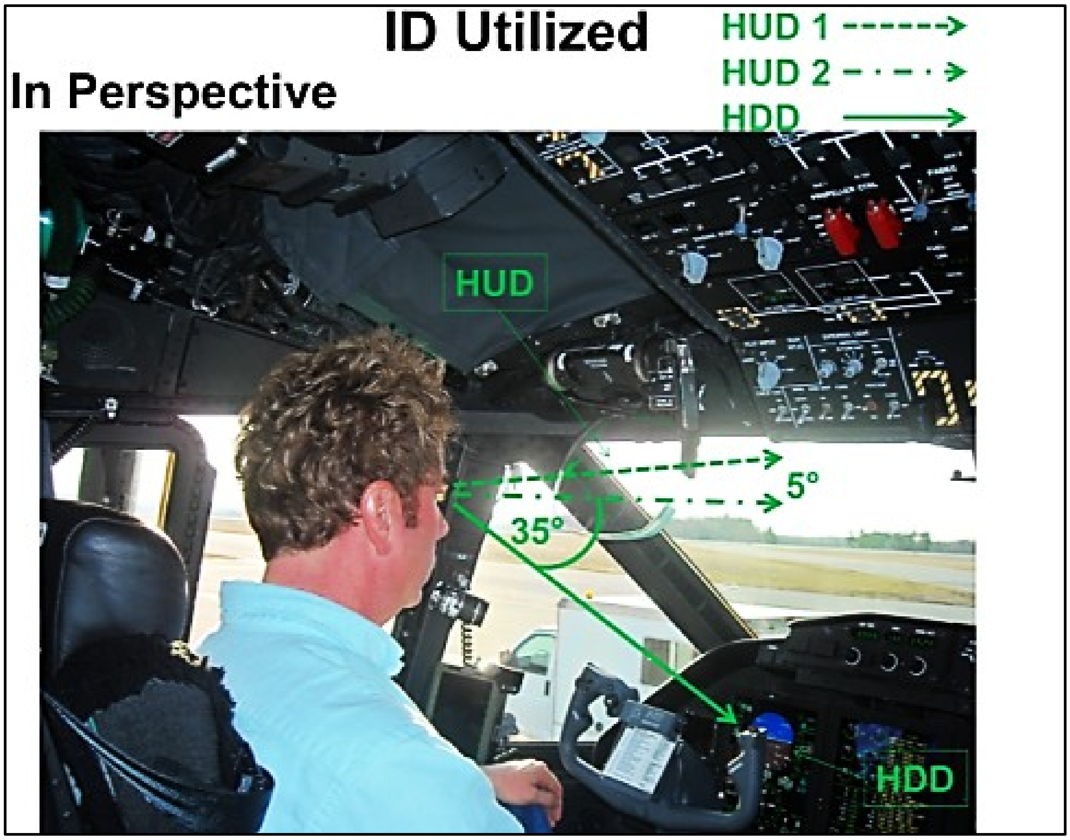

Figure 3. Photograph, pilot's LOS for HUD vs. HDD. This display manipulation induced variation in task difficulty, to observe differential effects on both subjective and objective psychophysiological measures (Capó-Aponte et al., 2009; Proctor & Vu, 2010).

Figure 4. Photograph, pilot’s view through the HUD and the outside environment. LOS matches FOV creating small to zero PRP, and consequently *low task difficulty*.

Figure 5. Photograph, pilot's view at the HDD (photo taken by researcher from jump seat). LOS does not match FOV creating large PRP, and consequently *high task difficulty*.

Neurocognitive Variables (IVs). There are three Independent Variables (IVs): Visual Attention (visual attentiveness and visual perceptiveness) [V_a, V_p] and Visuospatial Working Memory [V_{swm}] for the primary constructs of situation awareness and workload between the ID used. Visual Attention was measured by the IVA+. The IVA is based on a model that conceptualized attention as a multidimensional capacity that includes five primary factors including focused, sustained, selective, alternating and divided attention. Visual attentiveness and visual perceptiveness are quotient scores on the IVA+ scale, and therefore, the variables are reported as a standard score and have a ratio level of measurement. These standard scores have a mean of 100 and a standard deviation of 15. The test is integrated for both auditory and visual performance, and it was administered in that manner in order to preserve its validity and reliability. However, it does yield separate visual and auditory scores, for this research only the visual portion / scores were utilized (see Table 5).

Visual Attentiveness (IV). It is a composite quotient score that is derived from visual Vigilance, Focus, and Speed, involving both static and dynamic visual processing (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994). Visual vigilance is the maintenance of attention required to respond to a change in the environment (a state of inhibition) such as responding to a target. Intuitively, the mind can wander; the subject must maintain his or her attention in order not to miss a target. Visual focus is the consistency (lack of variance) in reaction time to a change in the environment and reflects the sustaining and maintaining of attention (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994). Visual speed is defined as the average reaction time to changes in the environment. This measures discriminatory mental processing speed. Both are measured in milliseconds. To elaborate, Visual Attentiveness (V_a) is the ability to concentrate and be devoted, to be diligent and detailed, alert, watchful, and responsive. This variable is derived from visual Vigilance, Focus, and Speed scales (Sandford &Turner, 2009). For salience, Vigilance is a measure of inattention as evidenced by two different types of errors of omission (seeks traits consisting of being intense and accurately responsive). To be vigilant, an individual must maintain and direct attentional effort to classify each stimuli as either a target or foil and then make the appropriate response (Sandford &Turner, 2009). Focus is the second major factor for V_a and reflects the variance in reaction time speed measuring the ability to sustain and maintain attention. The third major factor is Speed reflects the average reaction time for correct trials throughout the test, thus Speed measures discriminatory mental processing speed. Speed equals = Mean visual reaction time in milliseconds for all correct trials (Sandford &Turner, 2009). The Attentiveness score is very apropos to assessing inherent visual attention of the pilot because these factors are essential characteristics of a pilot or UAV operator when processing information from a display.

Visual Perceptiveness (IV). Visual perceptiveness is similarly a composite score based on three sub-scores. It consists of visual Prudence, Consistency, and Stamina and involves both static and dynamic visual processing (Brain Train, 2010; Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994). Visual prudence is the selection or choice of a correct response or responses in the environment (non-inhibited). That is being non-impulsive, the ability to not automatically react yielding an incorrect response in the changing environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994). Visual consistency is the ability to stay on task, respond reliably, making dependable responses in a dynamic environment (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994). Visual stamina is the lack of variability in a subject's response times in the environment. This is the ability to maintaining a sustained effort over time. (Brain Train, 2010; Corbett & Constantine, 2007; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994). These are measured in milliseconds. To elaborate, Visual Perceptiveness (V_p) is the ability to have a perceptivity, to be insightful, and to have discernment - the ability to perceive that which is obscured. For salience, Visual Perceptiveness is visual insightfulness or perceptivity and it is equivalent to: Prudence as a measure of Carefulness (anti-impulsivity) and response inhibition as evidenced by three different types of errors of commission(seeks traits of consisting of being circumspective and mindful), Consistency, which measures the general reliability and variability of response times and is used to help measure the ability to stay on task, and Stamina, which compares the mean reaction times of correct responses during the first 200 trials to the last 200 trials. This score is used to identify levels of sustaining attention and effort over time (Sandford & Turner, 1994, 1995). The Perceptiveness score is very apropos to assessing inherent visual attention of the pilot because these factors are essential characteristics of a pilot or UAV operator when processing information from a display.

Visuospatial Working Memory (IV). This is working memory that contains visual and spatial information that is stored in the visuospatial sketchpad in the mind (Baddeley, 2006), this immediate memory can be thought of as a workbench where material is continuously being combined and transformed. Visuospatial working memory was assessed via the spatial n-back task (Gevins & Cutillo, 1993), already explained in detail in this section along with its validity. This variable's level of measurement is ratio and is a percent of selections that are correct out of the total number of trials. Scores can range from 0% correct to 100% correct.

Situation Awareness (DV). This study was focused on situation awareness, and it is the psychological ability and capacity to perceive information and act on it acceptably. Previous research (Gutzwiller & Clegg, 2012; Svensson & Wilson, 2002) had also shown that mental workload is a component and predictor of situation awareness; consequently, workload was assessed as well to provide additional implicit measurements of SA for the ANOVA test. Mental workload is an implicit measurement of situation awareness; as mental workload increases, cognitive situation awareness decreases (Gutzwiller & Clegg, 2012; Kokar & Endsley, 2012; Svensson & Wilson, 2002; Wilson & Russell, 2003; Wilson, et. al, 2009). The Bedford Workload Scale and China Lake Situation Awareness Scale were administered to the pilots. This was the Dependent Variable (DV) and were the results from the self-reported levels of situation awareness and workload (Cohen & Cohen, 1983; Cohen, 1960), and as validation and verification Heart Rate Variability (HRV), Heart Rate (HR), the EEG (alpha and theta wave divergence) were measured as well.

Electroencephalography (EEG), as a psychophysiological measure, has been successfully used to estimate an operator's cognitive state (Wilson, 2007). First studied in animals by Richard Catton in 1875, electroencephalography is the study of the electrical activity of the brain (Wilson, 2007). It has been determined that superposition of post-synaptic potentials due to volume conduction causes the observable electric activity at the scalp (Wilson, 2007). Topographic EEG data will show changes in the scalp-recorded patterns of alpha activity that are consistent with the mental demands of the various segments of the tasks being performed (Wilson, in press). There are two ways to study EEG: time-locked to the stimulus (event-related or evoked potential) or spectral (windowed/averaged in time) (J.C Christensen, personal communication, Jan 10, 2012) (see Table 5).

Without an external stimulus, spontaneous EEG occurs, such as alpha and beta rhythms, whereas ERPs occur in response to a specific stimulus. Spontaneous EEG has been conventionally classified into five clinical frequency bands, derived via Fourier transform of time-series EEG data: delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-31 Hz), and gamma (31-43 Hz) (Wilson, 2007). To determine a person's cognitive state for use in applications such as workload assessment and adaptive automation, the spontaneous EEG has been widely used, even without specific events from which ERPs are obtained (Wilson, 2007).

During mentally demanding portions of tasks frontal theta-band EEG has shown increased activity (Wilson, 2007), therefore, theta-band EEG should increase as mental workload increases (Wilson, 2007). Topographic EEG data from 29 channels illustrated decreases in parietal alpha-band activity, which correlated to higher mental demands therefore, parietal alpha-band EEG should decrease as mental workload increases (Wilson, 2002). Multiple EEG recording sites are useful to detect significant changes in regional brain activity that are related to different tasks. It has been found that increases in cognitive workload were associated with decreased EEG alpha-band power over parietal scalp sites (Wilson, 2002), with corresponding increases in theta power. Therefore, theta and alpha diverge, when mental workload significantly increases (Hankins & Wilson, 1998). To summarize, psychophysiology measurements including the combination of ECG and EEG have shown a high level of accuracy and validity in explicitly measuring workload which in turn is implicitly measuring situation awareness (Gutzwiller & Clegg, 2012; Kokar & Endsley, 2012; Svensson & Wilson, 2002; Wilson & Russell, 2003; Wilson, et. al, 2009). As mental workload increases, cognitive situation awareness decreases (Gutzwiller & Clegg, 2012; Kokar & Endsley, 2012), consequently, as one measures the current psychological and physiological state of an individual, one is measuring mental workload and in turn, cognitive situation awareness (Gutzwiller & Clegg, 2012).

Data Collection, Processing, and Analysis

The fundamental analysis that addressed the research questions was the within-subjects and factors repeated-measures factorial ANOVA which was used to measure the main effects of the independent variables (task difficulty and visual ability) the interactions among the independent variables, the importance of the dependent variable (situation awareness), and the strength of association between these variables. There was a check at mid-way to look for dropouts.

Normality in the data was verified and a standard parametric statistical analysis was performed (Creswell, 2009; de Vaus, 2001; Moore, 2007). The ANOVA was used to look for a significant difference between means (Creswell, 2009; de Vaus, 2001; Moore, 2007). That is, it was used to see whether or not there was a significant difference between the average scores of the groups being tested.

In multivariate analysis, the composite variable is ubiquitous. The composite variable is derived by combining two or more variables linearly as in path analysis, or curvilinearly as in polynomial regression analysis. Each input variable is incorporated by assigning a weight and or order as appropriate, utilizing the multivariate technique. This research derived the composite variable [Predicted Situation Awareness (cognitive situation awareness and mental workload)], and on the basis of analysis, this composite variable was a function of: Information Display (ID) used, Visual Attentiveness, Visual Perceptiveness, and Visual Spatial Working Memory (Grim & Yarnold, 2006).

Assumptions

The participants were recruited at an Air National Guard base in central Ohio and were qualified pilots in the aircraft being used for the study. This resulted in relative homogeneity of the population that reduced nuisance variance. The analysis assumed that there was at least an approximate relationship between the predictors and outcome variables, that participants were independent of each other, and that the scores were approximately normally distributed. In the absence of prior research regarding the relationship between visual abilities, situation awareness, and cognitive workload, a relationship is a reasonable and pragmatic assumption. Participants were measured and sampled independently, so it was reasonable to assume that the scores were independent of each other and the data were examined and the data were verified to be normally distributed.

Limitations

Some of the pre-existing factors such as the subject pilot's previous experience using HUDs and his or her level of piloting skills were not taken into account. In addition, there are an untold number of possible outside influences that could have affected the results, such as sleep quality, family/emotional disturbance, diet, etc. (Cervone & Pervin, 2007). Additionally, there was not complete randomness. Even with these disadvantages, because the shortcomings were recognized throughout this study, and repeated measures were taken, the results are still valuable (Creswell, 2009; de Vaus, 2001; Trochim & Donnelly, 2008).

Delimitations

The primary purpose of this quasi-experimental quantitative study was to test visual perceptiveness, attentiveness, and spatial working memory as predictors of situation awareness. In order to maximize ecological validity and minimize nuisance variance due to heterogeneous participants, this project focused on the controlled assessment of the visuocognitive abilities of Air National Guard pilots, with actual piloting as a completely real task suitable for measuring resulting situation awareness.

This was the most effective and realistic method to perform the research that addressed the problem and the purpose. As an example alternative approach, a completely laboratory based study utilizing the typical convenience sample of college undergraduates could have been accomplished; however, one would expect large individual differences as well as serious concerns about the measurement of situation awareness outside any meaningful task context. The choice of participant population potentially limits the generalization of results to other populations, however this was a realistic and necessary delimitation in order to increase the chances of observing meaningful results and keep the study feasible in terms of sample size and associated costs. Another delimitation was the measures chosen; while other techniques for assessing SA could have been used (e.g., SAGAT; Endsley, 1995) the methods chosen were the most practical and effective in the aviation environment. Longer surveys or interruptions were not feasible due to real-world demands, but the surveys that were used were acceptable given the increased ecological validity.

Ethical Assurances

The ethics of this study were covered, addressed, and monitored throughout the study. The subjects flew aircraft with an associated minimal and low-risk level. Extensive consideration was given to the possible risks involved and possible mitigations for those risks. It was addressed as to why the study should be done in the manner chosen to conduct it—with pilots exposed to real risks, rather than using simulators. This study was conducted with an AFRL IRB and NCU IRB approval, participants completed comprehensive written informed consent, and multiple USAF board reviews were performed. Specifically, before the research and data collection was initiated an USAF Safety Review Board (SRB) and an USAF Flight Test Board (FTB) was conducted in addition to two Institutional Review Boards (IRBs): one carried out by the USAF and one conducted by NCU.

The rights, responsibilities, and safety of the researcher and subjects are and must be strictly respected at all times and were for this study (Creswell, 2009). To do this, there were key areas that were followed and adhered to during and after this research as they pertain to the ethical practice and relationship between researcher, psychologist, or specialist and subject, or participant. Before psychological research can begin, informed consent must be obtained. This was accomplished using an Informed Consent Document (ICD) that was read and completed by each and every subject involved in this experiment (Creswell, 2009). The researcher has the responsibility of guarding the confidentially of each individual subject, and this occurred during and after this study (Creswell, 2009). The IVA and V_{swm} data obtained was for research purposes only and was not used in any type of medical capacity, nor was the ECG and EEG collected data. To name a few items, the researcher must and did provide, participants information regarding the research purpose, the procedures, the possible benefits and risks of adverse outcomes, rights and responsibilities of subjects, limits of confidentiality and what can be expected from the researcher (Creswell, 2009).

Summary

The understanding of SA lacked a level of detail to account for psychological mechanisms needed to predict the outcome (Endsley, 1999; Jodlowski, 2008). Even though SA is considered a cognitive engineering construct there were no direct objective psychophysiological or psychological measurements for predictors of it. There was no consensus on predictors for SA and this area had tended to be elusive.

This study was intended to discover the relationships between perceptual effects caused by ID designs' spatial location, inherent neurocognitive factors, and changes in SA and WL. Most SA and WL studies had been performed with the use of the flight simulator or in the laboratory, and used solely subjective measurements. However, very little prior research had examined cognitive phenomena (mental WL and resulting SA), in an actual aircraft during flight. Likewise, previous research had not examined the relationships between individual visual abilities and resulting levels of SA and WL during complex multitasking.

A within-subjects quasi-experimental repeated-measure design was used that incorporated neurocognitive SA and WL measurement. All participants were pilots qualified in the aircraft. Subjects filled out a SA scale, a WL scale, and a modified Primary Flight Display (PFD) evaluation questionnaire after each sortie and the psychophysiological measurements including electrocardiography (ECG) and

Electroencephalography (EEG) were collected per sortie for comparisons within group and between groups (HUD and HDD). Results were analyzed using traditional parametric approaches (ANOVA, correlation) to test for significant relationships between visual abilities, WL, and SA, whether assessed subjectively or neurocognitively.

Chapter 4: Findings

Visual processing can be categorized as static and dynamic (Proctor & Vu, 2010), and may be operationalized as visual attentiveness and perceptiveness, integrated with visuospatial memory (Brain Train, 2010; Christensen et al., 2013; Corbett & Constantine, 2007; Endsley, 2012; Gugerty, in press; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). Consequently, the primary purpose of this quasi-experimental quantitative study was to test the predictive value of these specific candidate visuo-cognitive abilities: (a) Visual Attentiveness, consisting of Vigilance, Focus, and Speed, (b) Visual Perceptiveness, consisting of Prudence, Consistency, and Stamina, and (c) Visuospatial Working Memory, which consists of Working Memory that is stored in the visuospatial sketchpad in the mind, as predictors of situation awareness, e.g. the effects of visual ability on the level of situation awareness. Therefore, this project tested the predictive value of these variables as factors between a particular task to be performed and the eventual outcome of situation awareness, in order to examine if there was a potential relationship between the neurocognitive factors of visual attentiveness, (Hypotheses 1), visual perceptiveness (Hypotheses 2), and/or visual spatial working memory (Hypotheses 3) and situation awareness. These neurocognitive factors were derived from visual processing that can be categorized as static and dynamic, and may be operationalized as visual attentiveness and perceptiveness, integrated with visuospatial memory and measured by the IVA+ and N-back tests.

As Pavlov, Watson, and Skinner performed field experiments in order to contribute to psychological theory (Cervone & Pervin, 2007), a field experiment in the paradigm of neuroergonomics (Parasuraman, Christensen, & Grafton, 2012) employing quasi-experimental repeated-measures (within-participants), was used for this study. This further inquiry involving visual cues clarified the role of these abilities in order to make theory-driven predictions for situation awareness (Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens & McCarley, 2008).

These pilots were recruited at an airport in north central Ohio by utilizing a recruitment memo and posters in squadron buildings. All participants were pilots qualified in the aircraft. There were two display conditions that varied the difficulty of maintaining SA by changing the presence and position of the information display. The first condition had an Information Display (ID) design that was near optimal and centered on the pilot's field of view and was no more than five degrees above or below the pilot's line of sight (Harbour, Hudson, & Zehner, 2012). The second condition had an ID design that was suboptimal and well out of pilot line-of-sight (a 35-degree vertical drop) (Harbour et al., 2012).

The experimental study of situation awareness presents particular challenges. Situation awareness is highly context-specific; experimental testing and manipulation must be conducted with respect to an actual task. As previously discussed, it is a complicated tangible that is not well addressed by impoverished laboratory study focusing on simple, artificial tasks. Consequently, the use of a meaningful, consequential task context is essential to the study of situation awareness. This chapter will review the findings of this study by binding the purpose around the research questions and resulting hypothesis.

This quantitative research utilized a quasi-experimental design that made use of repeated measures comparisons, with situation awareness as the dependent variable. The within-subjects and factors repeated-measures ANOVA was used to measure the effects of the variables (independent / dependent), their interactions and importance, and the strength of association between variables. Each subject in the experiment was exposed to all levels and conditions. As mental workload goes up, cognitive situation awareness goes down (Gutzwiller & Clegg, 2012; Kokar & Endsley, 2012), consequently, as one measures the current psychological and physiological state of an individual, one is measuring mental workload and in turn, cognitive situation awareness (Gutzwiller & Clegg, 2012). Succinctly put, as one measures mental workload one implicitly measures situation awareness (Gutzwiller & Clegg, 2012; Kokar & Endsley, 2012). In order to explore visual abilities as predictors of situation awareness with factors between task difficulty and situation awareness, the following research questions sought to address the overarching question of identifying predictors of situation awareness under varying task difficulty.

In all three below questions, the visual abilities were evaluated as predictors (factors) of situation awareness. Task difficulty, in and of itself, was analyzed as a necessary manipulation check to verify that the conditions produced significant main effects in situation awareness; however this was not a central research question. A main effect of visual ability was probed to determine which abilities contributed to observe variation in situation awareness, likewise any interaction between visual abilities and task difficulty were assessed. Additionally multiple regression analysis was performed. The bottom line is what were the effects of visual ability on the level of situation awareness?

To review, a detailed investigation that focused on the following main research questions was performed:

Q1. Under varying task difficulty, are there statistically significant effects of subject inherent visual attentiveness on situation awareness?

Q2. Under varying task difficulty, are there statistically significant effects of subject inherent visual perceptiveness on situation awareness?

Q3. Under varying task difficulty, are there statistically significant effects of subject inherent visual spatial working memory on situation awareness?

To address the research questions, the following hypotheses were tested:

H1$_0$. Under varying task difficulty, there will be no statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H1$_a$. Under varying task difficulty, there will be statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H2$_0$. Under varying task difficulty, there will be no statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H2$_a$. Under varying task difficulty, there will be statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and

Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

$H3_0$. Under varying task difficulty, there will be no statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

$H3_a$. Under varying task difficulty, there will be statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

A sample of 19 C-27J pilots, at the 179th Airlift Wing (AW) (see Appendix A for List of Acronyms), were tested with a neurological assessment to examine if neurocognitive factors could predict levels of situational awareness (see Appendix B). This chapter includes the statistical assumptions that were utilized, the descriptive results of participant demographic data, and the procedures used to test the three hypotheses that were examined to describe the results of the study.

The within-subjects and factors repeated-measures ANOVA was used to measure the effects of the variables (independent / dependent), their interactions and importance, and the strength of association between variables. The Pearson's product-moment correlation was used to examine the correlations and relationships between visual abilities and situation awareness. Multiple regression analyses was used to investigate the predictor significance and variances of the predictors (i.e., independent variables) and the dependent criterion variable, in order to derive a mathematical equation for SA as a function of V_a, V_p, and V_{swm}. This chapter ends with a discussion, evaluation, and synopsis of the findings regarding whether specific neurocognitive abilities have a role in predicting and determining situational awareness.

Assumptions Made in the Statistical Analyses

There were several assumptions that underlay the statistical analyses, before project execution *a priori* power analysis was performed with required assumptions. After project implementation, a post hoc power analysis was performed and the ANOVA assumptions of normality, independence, and homoscedasticity were verified, along with the assumptions of multiple regression analysis that include those same assumptions plus linearity, multicollinearity, singularity, absence of outliers, and statistical independence of the errors.

In keeping with fundamental human subjects' research protections, this study relied on volunteers from the population, with the total number goal at the minimum necessary to accomplish study goals based on *a priori* power analysis. Therefore, in advance of doing this study one must estimate the effect size in the study (NCU, 2011). Lipsey and Hurley (2009) describe a way to estimate effect size by reviewing the literature on the same or similar relationships or interventions to find the range of relevant effect sizes to estimate the effect size for one's study. In the literature usability problems or excelling attributes with varying display designs (the varying of task difficulty) are likely to be detected with an effect size of approximately 0.4 (Jacko, 2012; Lewis, 1994, 2001, 2006; Nielsen, Jakob, & Landauer, 1993; Nielsen, 2000, 2004; Sauro & Lewis, 2005; Virzi, 1990; Smith, 2001). Caulton (2001) indicated that a modest effect estimate such as this should only be used if given a firm homogeneity assumption – that is the types of participants being sampled will have the same probability of encountering usability issues based on the characteristics of the participants and therefore the resultants are influenced by that modest effect estimate. The assumption of homogeneity is reasonable given the population of selected Ohio ANG pilots flying the same type aircraft; consequently, the moderate effect size of 0.4 was appropriate for power analysis.

G*Power 3.19 was used to conduct *a priori* power analysis. The appropriate statistical test chosen was the ANOVA: Repeated measures, within factors. The same pilots flew using the two different display designs in order to vary task difficulty, and exhibited a range of the three visual abilities (perceptiveness, attentiveness, and spatial memory). Each condition was repeated a minimum of four times.

Therefore, *a priori*, computed sample size required for a given power, alpha, and effect size was calculated, using the ANOVA: Repeated measures, within factors with a moderate effect size of 0.40, the power was set to a minimum to the desired level post hoc of 0.8 and the alpha error probability was set to 0.05 (for one tail) yielding a minimum sample size of 12 participants and a critical F of 3.1599. This suggested that approximately 12 participants should result in an adequately powered study (see Table 4: *A priori: Computed Required Sample Size*). Even though there were a total of 19 participants only 12 were in each condition repeated four times; therefore, the statistical tests for the hypotheses and study results answering the research questions are based on those twelve subjects. Consequently, this led to a decrease in the potential for a Type I error, in addition, this computed sample size was associated with an increase in the power and a reduction in Type II error (Cozby, 2006). The researcher did achieve statistical power for statistical analyses at a power $1- \beta = 0.98$, $\alpha = .05$, and effect size (see Table 7 and Table 9), minimizing Type I and Type II errors.

Post hoc, as the dependent variable is continuous, an effect size of the d family of standardized mean differences could be considered (Cohen, 1988). However, the effect size measure Cohen's f^2 (Cohen, 1988) is appropriate for calculating the effect size within a multiple regression model in which the independent variables of interest are multivariate (such as V_a, V_p, and V_{swm}) and the dependent variable (SA) is continuous and repeated measures of subjects utilized (such as 4-times) (Friedmann et al., 2008; Selya, Rose, Dierker, Hedeker, & Mermelstein, 2012) . Cohen's f^2 is commonly presented in a form appropriate for global effect size:

$$f^2 = \frac{R^2}{1 - R^2}$$

Consequently, the effect size

$$f^2 = \frac{(0.75)^2}{1 - (0.75)^2}$$

Hence, therefore

$$f^2 = 3.05$$

Table 6

Model Summary

Model Summary				Change Statistics					
	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
	.868[a]	.753	.660	.18356	.753	8.125	3	8	.008

a. Predictors: (Constant), Vswm, Va, Vp

Table 6 illustrates that together V_{swm}, V_a, V_p, account for 75.3 percent of the variance in SA, $p<.05$.

Table 7

Post hoc: Computed Achieved Power

F tests - Linear multiple regression: Fixed model, R^2 increase		
Analysis:	Post hoc: Compute achieved power	
Input:	Effect size f^2	3.05
	α err prob	0.05
	Total sample size	12
	Number of tested predictors	3
	Total number of predictors	3
Output:	Noncentrality parameter λ	36.6000000
	Critical F	4.0661806
	Numerator df	3
	Denominator df	8
	Power (1-β err prob)	0.9831082

Table 7 illustrates the Post hoc: Computed Achieved Power as computed by G*power, Power = 0.9831.

The goal of hypothesis testing with the ANOVA is to determine whether the means of the sample differ more than you would expect if the null hypothesis were true. The tests were statistically significant for the three predictor visual abilities V_p, V_a, and V_{swm} as task difficulty was varied, $F(3,11) = 8.125$, $p = .008$. Specifically, V_a [$F(2,11) = 5.749$, $p = .025$], V_p [$F(2,11) = 12.125$, $p = .003$], and V_{swm} [$F(2,11) = 8.397$, $p = .009$]. In addition, certain requirements and assumptions must be met and or addressed for the

ANOVA to be useful. The use of the ANOVA is based on the assumptions that the SA distribution follows a normal curve, equal variances are present across conditions, and the observations are independent. To address the assumption of normality of the SA distribution and homogeneity of variance (homoscedasticity), the normality of the distribution of the dependent variable data must be examined first to ensure it is parametric (Dover, 1979). This was accomplished and pointed toward a very small negative skewness = - 0.029 and kurtosis ($K = -0.153$) of the frequency distribution of the sample and this was and is very close to zero, indicating a normal distribution (see Appendix B) (Dover, 1979). Additionally, a z-score was computed to verify the critical value of $\pm$ 1.96 and if normality significantly exceeded this value (Tabachnick & Fidell, 2007). To determine the critical value, the skew = -0.029 was divided by the standard error of skew = 0.637 and as a result produced a z score = -0.45; this is well within the p=0.05 threshold of z=±1.96, therefore skew was not significant. In addition, the graph illustrates that the distribution was evenly distributed, and skewness is within the range of ± ½ (skewness = -0.029) (Wuensch, 2005a), and kurtosis is within the range of ± 3 (K = -0.153) and is very close to zero (Wuensch, 2005b) (see Appendix B). Consequently, the distribution is parametric and the Levenes’s test for the equality of variances may be used.

Next, homoscedasticity was tested by the Levene’s test for homogeneity for V_p, V_a, and V_{swm} after sorting each of these independent variables into three equal and logical groups. Therefore, the neurocognitive factors were placed into consistent and plausible categorical levels. Homogeneity of variances were successfully tested for the SA distribution, V_p (Levene’s statistic = 0.339, df 2,9, p = 0.721), V_a (Levene's statistic =

0.469, df 2,9, p = 0.640), and V_{swm} (Levene's statistic = 0.382, df 2,9, p = 0.693). Consequently, the null hypothesis cannot be rejected, therefore the groups have equal variances and are homogeneous, hence the existence of homoscedasticity. For this study, the observations were independent and the samples as random as feasibly possible (near-random) given the nature of this field experiment. The samples were indeed from the population of ANG pilots in Ohio and were, therefore, representative. Additionally, the value of one observation was not related to any other observation and none of the subject's scores provided any clues as to how any of the other subjects should score nor were any of events dependent on another. Consequently, the observations were independent.

Moreover, the additional assumptions of multiple regression analysis of linearity, singularity, multicollinearity, absence of outliers, and statistical independence of the errors were also verified. The majority of the variance in situation awareness is accounted for by the multiple regression model consisting of V_p, V_a, and V_{swm}, R^2 = 0.753, p = .008, with a calculated Durbin-Watson statistic of 1.425. This is a value near 2.0, which indicates non-autocorrelation. Had it been closer to 0 or 4.0 it would show positive autocorrelation or negative autocorrelation, respectively. The residuals are not autocorrelated. Together, these validate the assumptions of linearity and statistical independence of the errors. Additionally, multicollinearity artificially inflates the variances of the parameter estimates; therefore, this could lead to the lack of statistical significance of the individual predictor variables even though the overall model may be significant (Tabachnick & Fidell, 2001). The Variance Inflation Factor (VIF) quantifies the severity of multicollinearity. The VIF is an index, which measures how much variance of the estimated regression coefficient is increased because of multicollinearity. If any of the VIF values exceed five (5.0), it could be inferred that the associated regression coefficients are poorly estimated because of multicollinearity (Montgomery, 2001). V_p (VIF = 1.504 < 5), V_a (VIF = 1.246 < 5), and V_{swm} (VIF = 1.647 <5). Consequently, multicollinearity, was and is not an issue with the study results, the assumption of a non- multicollinearity remains valid. If these violations had occurred, the predictive variables could have become redundant with each other, and in that case one predictive variable would not add any analytical significance over another (Tabachnick & Fidell, 2001). This did not occur. Furthermore, the SPSS will exclude or not allow a variable of low tolerance to enter the regression model. If a singularity was present, SPSS would not have completed the multi-regression analysis and would have provided error messages in the results matrix. In addition, if multicollinearity had existed, the results would be unstable and the assumption would be violated. Furthermore, the independent variables would become redundant with the other predictor variables in the regression model. This did not occur. This study did not violate singularity assumptions.

For the assumption of the absence of outliers and more on the linearity assumption, a normal probability plot of a regression for SA was constructed to observe the data distribution for V_p, V_a, and V_{swm} (see Appendix B). This was indicative of the normal line value for the distribution and in appearance; the distributions are precisely linear with no prominent outliers present. The normal probability plot analyses in this study showed a linear line from the upper left to lower right indicating a normal distribution of the criterion dependent variable scores of SA as a function of V_p, V_a, and

V_{swm} (Tabachnick & Fidell, 2001). The quasi-experimental quantitative method and statistical design did not violate this assumption.

Furthermore, the assumptions of normality, homoscedasticity, and linearity were not violated in this study. Scores (i.e., neurocognitive predictor variables) in the study were examined for probable issues that could affect the homoscedasticity as > 2 *SD* from the mean. To examine if any issues affected the distribution, a Cook's *Di* (i.e., distance) statistical analysis was computed. Cook's *Di* value range begins at zero and as *Di* becomes larger; more issues may become significant and influence the linear regression results. The *Di* threshold point is *Di* > 1 or more conservatively *Di* > 0.078 (Cook, 1977). The results indicated that the Cook's *Di* = 0.001 (*SD* = 0.824). As a consequence, no issues were not significant and did not influence the results; therefore, all the data were included in the analyses. The study's statistical data analysis assumptions were not violated in the ANOVA tests, multiple regression assumptions, and the Pearson's product-moment correlations. In the following sections, the demographic sample is described along with the statistical procedures used to analyze the research questions and tests the hypotheses.

Results

The demographic characteristics are presented first for the total participant sample (N = 19). The demographic characteristics examined in the study were age, gender, and education level at testing. Additionally, all 19 subjects where highly trained and experienced USAF pilots that were fully qualified in the C-27J and all had over 1,000 hours of military flight time. Following the demographic characteristics, the hypotheses and research questions are discussed. Participants were not divided into groups, but instead performed repeated trials in all conditions repeated a minimum of four times and this contributed to a reduction in the subject pool to twelve. Specifically, a total of 7 subjects dropped out of the study over time, either because of transfer to another base or election to not participate in all aspects of the study.

Age. The age range of the sample was 31 to 47 years. Figure 6 shows the frequency of the demographic characteristics of the group age in the study population. The modal ages were 35 and 46-47 (both n = 4), which together comprised 50% of the 16 participants that answered the age question. The least frequent ages were 31, 32, and 39-45 (n = 1) (see Figure 6).

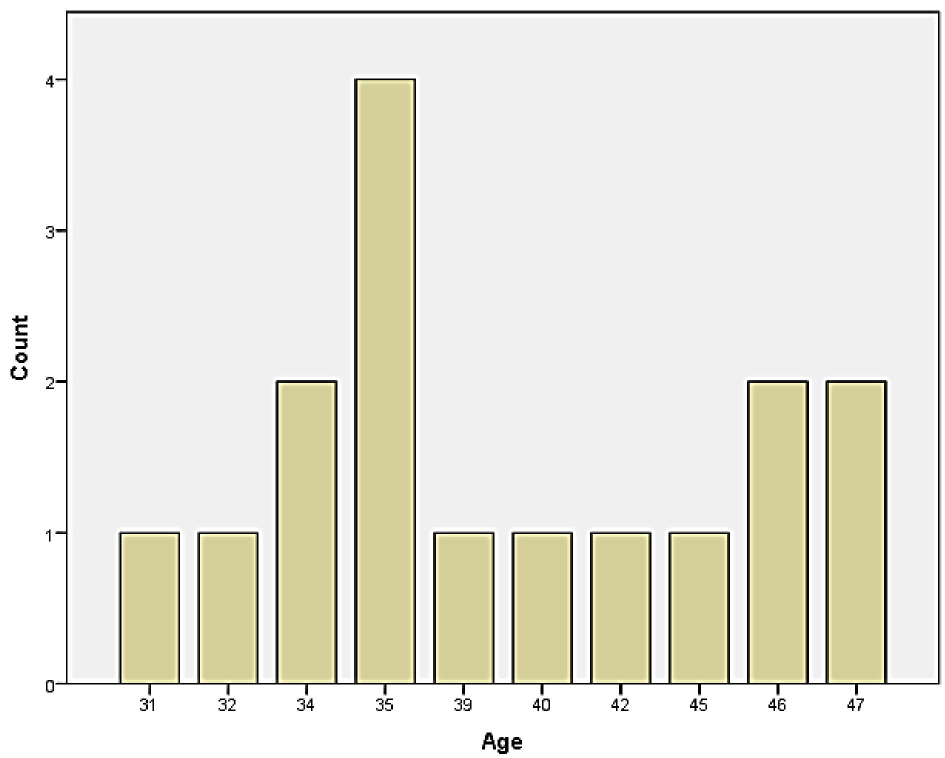

Figure 6. Age Demographics.

Gender. The sample was comprised of 19 participants of whom the minority was one female participant and the majority were 18 male participants. The gender ratio was 18:1; while highly skewed this is consistent with the population of Air National Guard pilots (USAF, 2007).

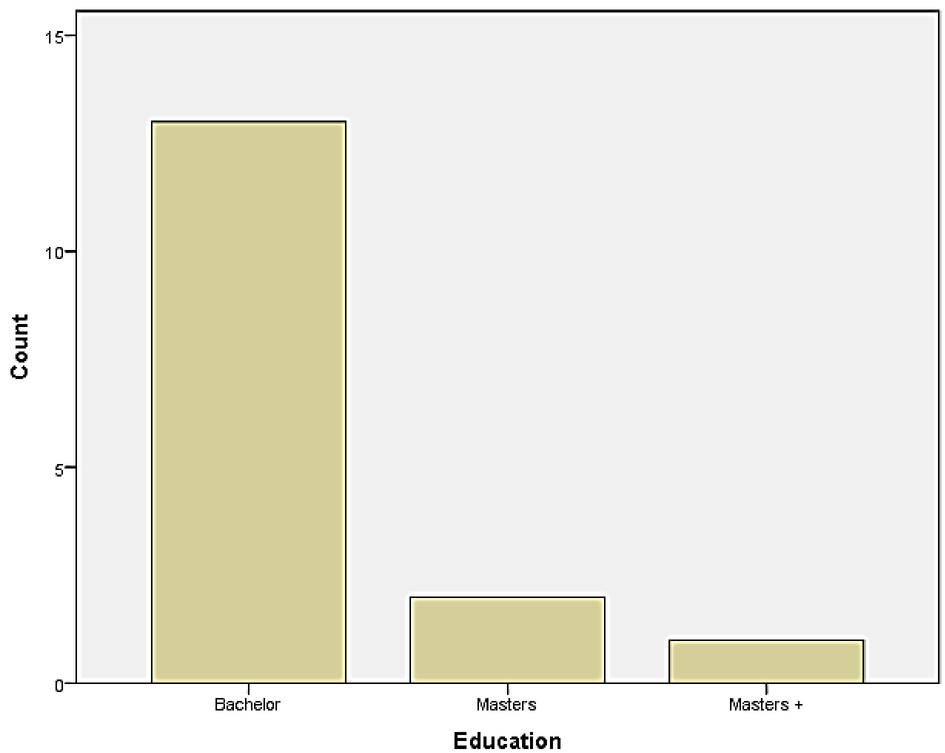

Figure 7. Education Demographics.

Education Levels. The education level range of the sample was from Bachelors' Degree to Masters' plus degree. Figure 7 shows the frequency of the demographic characteristics of education levels in the study sample. The most frequent education level was Bachelor's Degree, which comprised 70% of the participants (n = 13). Two participants had Masters' degrees, and one had a Masters' plus (see Figure 7).

Table 8

Descriptive Statistics of Demographics

Descriptive Statistics of Demographics				
	Range	Mean	Std. Dev	N
Age (yrs)	31 – 47	38.15	5.41	16
Education	Bach – Master+	Bach*	N/A	16
Female	1	N/A	N/A	19
Male	18	N/A	N/A	19

*Mode

Table 8 illustrates the resultant demographics for Age, Education Level, and Gender.

It was determined that during analysis it was best to use a composite SA score that consisted of combining both the China Lake and Bedford self-report survey scores (Bedford Workload Scale, Roscoe, & Ellis, 1990; China Lake Situation Awareness Scale, Adams, Kane, & Bates, 1998) and taking the average with equal weights producing a more sensitive overall self-report SA score, followed-up by using the objective psychophysiological measurements to validate and verify the computed composite SA score. Moreover, this best measures this dissertation's derived definition of situation awareness which is the psychological ability and capacity to perceive information and act on it acceptably. Consequently, this was verified by the corresponding HR and HRV objective measurements on each of the 12 subjects and the four subjects that additionally had reliable EEG data (see Table 13 and Figures 8, 9, 10, and 11). The China Lake survey was initially derived from the Bedford survey and therefore both are metaphorically familial and extremely similar (Banbury, Andre, & Croft, 2000). The only differences are in the way the questions are asked - in effect, they are alternate forms of the same questions. For example the China Lake asks the pilot to self-assess knowledge level (ability) of aircraft state, tasks (if task shedding needs to occur), and or environment, whereas the Bedford asks the pilot to self-assess capacity to have knowledge of aircraft state, tasks (if task shedding needs to occur), and or environment. All subjects responded between a one and five on both surveys for all events throughout varied task difficulty. One through five are a nearly a one-to-one relationship between the surveys, however, it was noticed that even though the subject would answer both surveys very similarly, repeatedly every subject would answer the China Lake one interval above the Bedford for the same identical tasks. It was observed that the pilot subjects would underreport their SA difficulty and overinflate their knowledge of aircraft state on the China Lake, likely due to the fact it contained in the title the words "Situation Awareness Level". The pilots tended to have a perceived pressure to fully handle all challenges and avoid triggering additional follow-up if they admitted to having "bad SA" whereas, they were more forthcoming in describing their workload level. It was, therefore, more apropos to using a Composite SA score between the two surveys that was verified by corresponding HR and HRV objective data. Additionally, the researcher observed that during high task difficulty the pilot would tend to commit minor, non-safety critical errors such as missing some of the radio calls, overshooting altitude level offs, target airspeeds, and generally flying a less stable platform. In these situations, the pilot would be more forthcoming in their self-assessment on the Bedford mental workload scale but less forthcoming on their self-assessment on the China Lake situation awareness scale, when logically both surveys should have been a one-to-one and equal type relationship. However, repeatedly the pilot rated his or her own SA as one interval higher than their own workload, consequently applying equal weights to both surveys and then taking the average for a composite SA score was the most conservative and reasonable solution to maximizing the validity and sensitivity of the SA assessment.

Figure 8. Photograph, ensuring electrical conductivity during EEG Leads and Cap Installation of EEG before flight.

Figure 9. Photograph, ECG Lead Installation (pre-flight).

SA, HR, HRV, Vp, Va, and Vswm.

Table 9

Descriptive Statistics of Variables

Descriptive Statistics of Variables				
	Range	Mean	Std. Dev	N
SA (Composite Score) Interval Level	1.875 – 3.0	2.4238	0.31492	12
HR (bpm) Ratio Level ≙	76.97 – 102.27	+ 25.3	N/A	12
HRV (ms) Ratio Level ≙	71.63 – 45.17	– 26.46	N/A	12
V_p (Quotient Score) Ratio Level	28 – 119	88.4167	26.92568	12
V_a (Quotient Score) Ratio Level	45 – 128	93.2500	23.38269	12
V_{swm} (percentage) Ratio Level	50 – 98	81.6667	15.39382	12

Table 9 illustrates study results for SA, HR, HRV, Vp, Va, and Vswm.

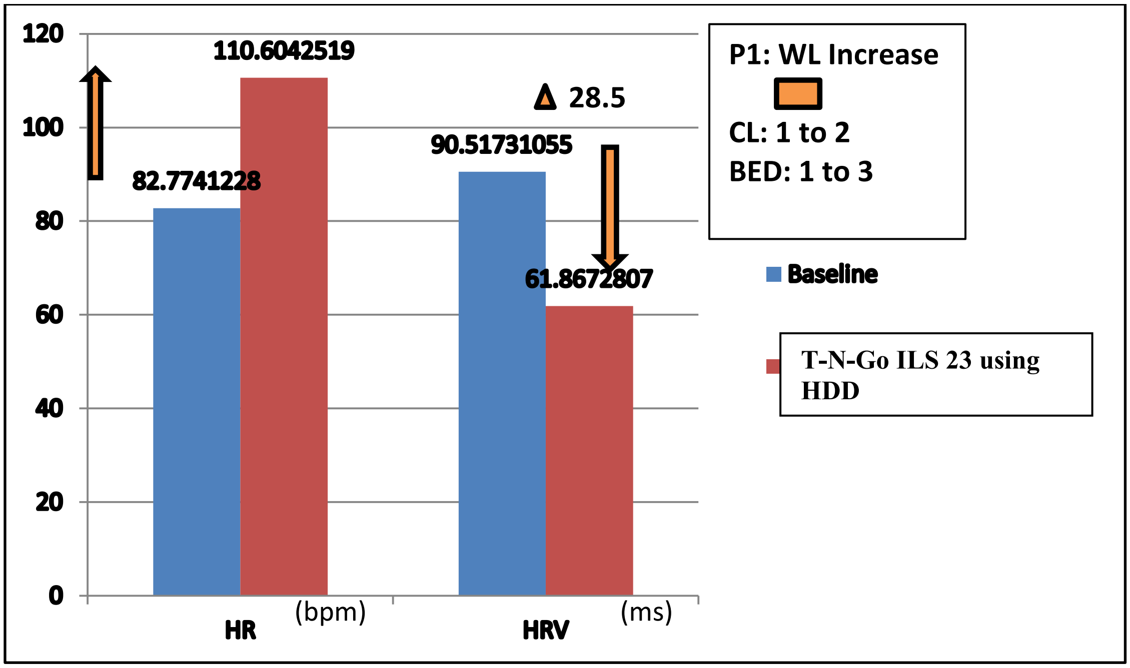

Figure 10. Typical HR increase and HRV decrease as composite SA score changes (China Lake and Bedford increase [SA is going down and WL is going up]).

Typical HR Increase and HRV Decrease as SA Decreases.

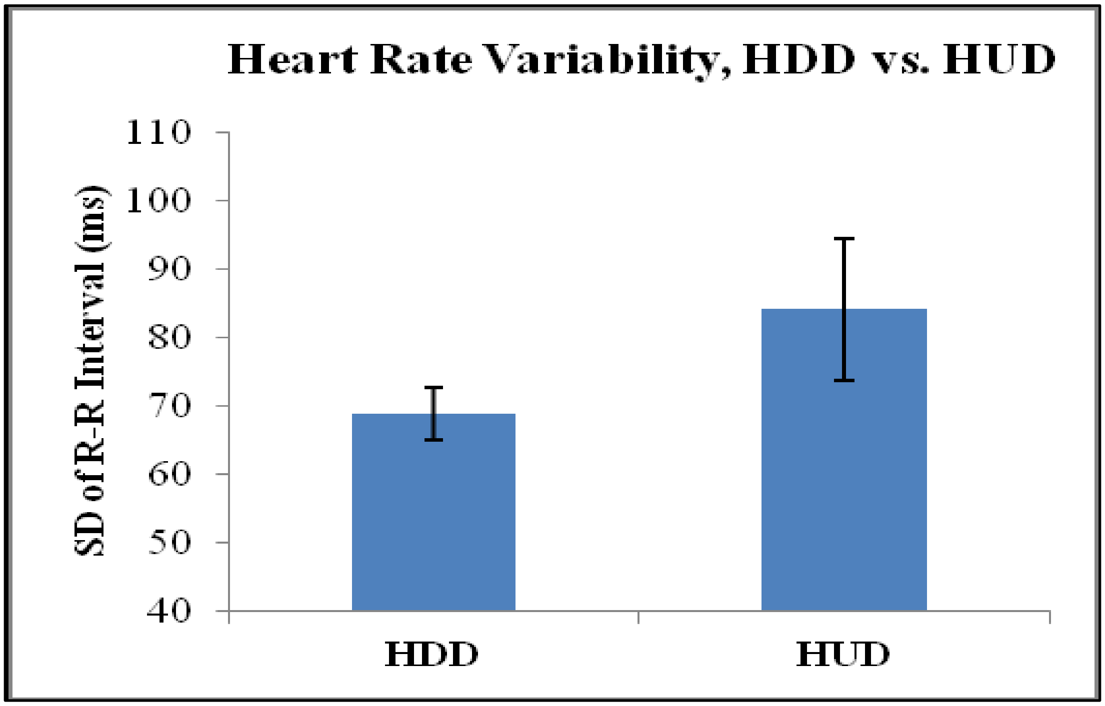

Figure 11. Average SDNN for instrument approaches conducted heads down (HDD) versus heads-up display (HUD). Bar height represents the mean, and error bars are one standard error of the mean. Note that lower values are associated with decreased SA and increased WL.

HRV: HDD vs HUD.

Inter-beat intervals were exported for subsequent analyses of average HR and SDNN (in this case, standard deviation of the R-R interval) by way of Fourier analysis using MATLAB (see Table 9, Figure 9, Figure 10, 11, 12, and Table 10).

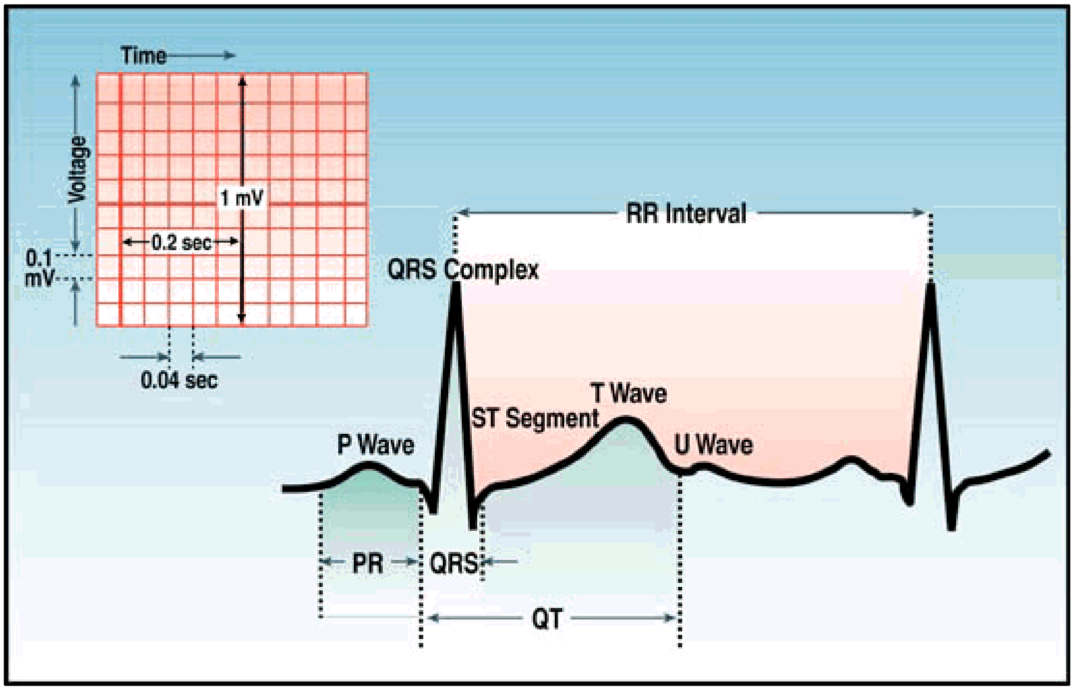

Figure 12. Illustrating R-R Interval (Wilson, 2002).

The Fourier transform was used in MATLAB to obtain the HRV spectrum.

$$X(f) = \int_{-\infty}^{\infty} x(t) \cdot e^{-2j\pi f t} dt$$

$$f(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{i\omega x} d\omega$$

$$F(\omega) = \int_{-\infty}^{\infty} f(x) e^{-i\omega x} dx$$

Specifically, the Fast Fourier Transforms were applied to the IBI sequence. Additionally they were used for EEG data analysis.

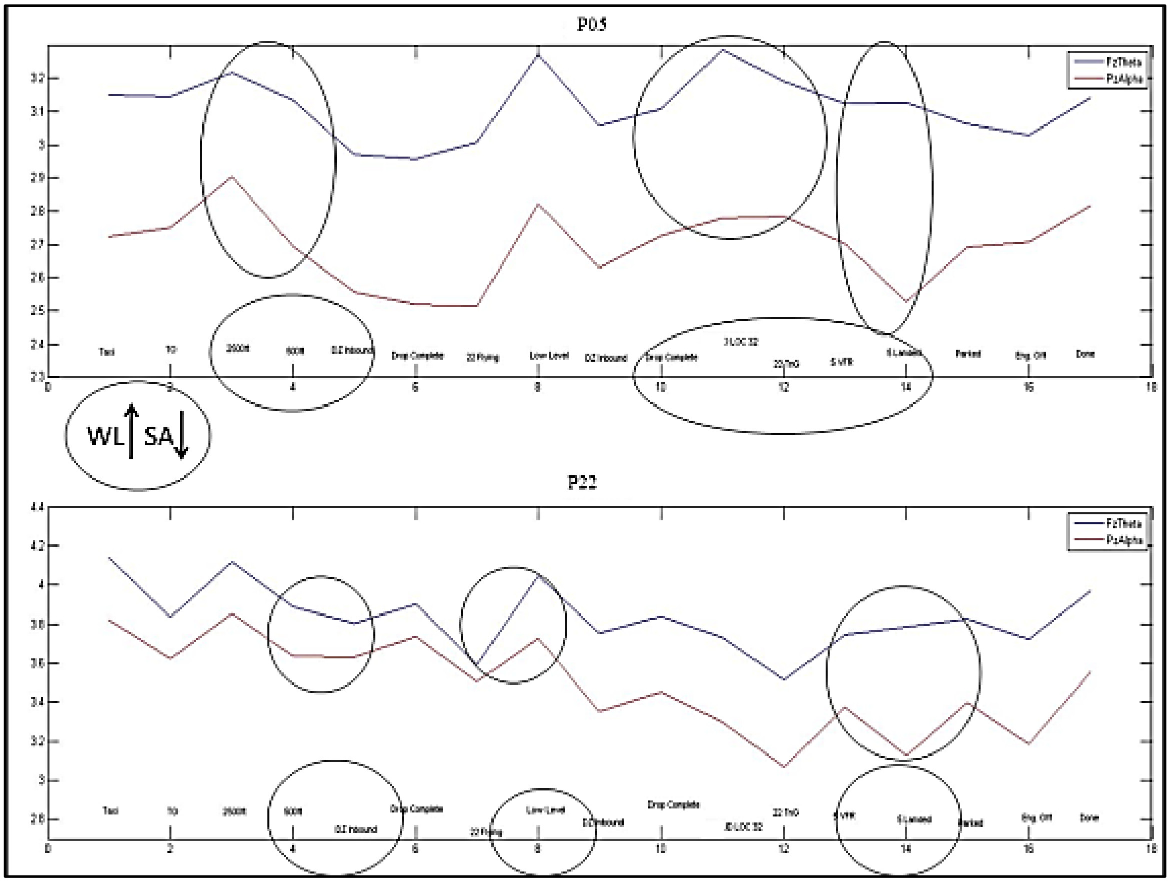

Figure 13. EEG variable.

Circled areas in Figure 13 illustrate increased workload and lowered SA. This is where P_z Alpha and F_z Theta brainwaves (electromagnetic energy) diverge in electrical power. Note, that in the top plot, while using the HDD on the VFR final approach and landing the pilot experienced an increase in mental workload and a decrease in cognitive SA. P5's P_z Alpha and F_z Theta brainwaves diverge most notably, while P5 also experienced a drop in HRV of 31.4 ms, while at the same time P5's composite SA score went from a score of 2 to 3.

Pz Alpha and Fz Theta Brainwaves Diverge as SA is Reduced.

For Entire Flight:

Table 10

Correlations

Correlations		SA	Vp	Va	Vswm
Pearson Correlation	SA	1.000	-.816	-.402	-.705
	Vp	-.816	1.000	.331	.571
	Va	-.402	.331	1.000	.433
	Vswm	-.705	.571	.433	1.000
Sig. (2-tailed)	SA	.	.002	.048	.01
	Vp	.002	.	.147	.026
	Va	.048	.147	.	.080
	Vswm	.01	.026	.080	.
N	SA	12	12	12	12
	Vp	12	12	12	12
	Va	12	12	12	12
	Vswm	12	12	12	12

SA = Dependent Variable

Correlations		Overall	Hard	Easy
Pearson Correlation	Vp	-0.816		
	Va		-0.583	
	Vswm			-0.634
Sig. (2-tailed)	Vp	0.002		
	Va		0.046	
	Vswm			0.026
N	Vp	12	12	12
	Va	12	12	12
	Vswm	12	12	12

Table 10 illustrates the Pearson Correlation between the variables (SA, V_p, V_a, and V_{swm}) as task difficulty varied, the 2-tailed significance levels, and N-the number of subjects.

Table 11 *Factorial ANOVA - Repeated Measures within Subjects.*

For the Overall Sorties

Dependent Variable: SA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.087[a]	9	.121	71.106	.014
Intercept	51.844	1	51.844	30508.734	.000
Vp	.197	2	.098	57.875	.017
Va	.060	2	.030	17.729	.053
Vswm	.006	2	.003	1.807	.356
Vp * Va	.000	1	.000	.182	.711
Vp * Vswm	.007	1	.007	4.160	.178
Va * Vswm	.000	0	.	.	.
$V_p * V_a * V_{swm}$	.000	0	.	.	.
Error	.003	2	.002		
Total	71.586	12			
Corrected Total	1.091	11			

a. R Squared = .997 (Adjusted R Squared = .983)

Table 11 illustrates the Factorial ANOVA - Repeated Measures within Subjects with SA as the dependent variable.

Table 12

ANOVA

ANOVA[a]					
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	.821	3	.274	8.125	.008[b]
Residual	.270	8	.034		
Total	1.091	11			

a. Dependent Variable: SA

b. Predictors: (Constant), Vswm, Va, Vp

Table 12 illustrates that the multiple regression within factors and repeated measures ANOVA was significant for the predictors' (Independent Variables: Vswm, Va, and Vp) effects on the criterion (Dependent Variable) SA, $p < 0.05$.

Table 13

Model Summary

Model Summary					Change Statistics				
	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
	.868[a]	.753	.660	.18356	.753	8.125	3	8	.008

a. Predictors: (Constant), Vswm, Va, Vp

Table 13 illustrates that together V_{swm}, V_a, V_p, account for 75.3 percent of the variance in SA, $p < 0.05$.

Table 14

Coefficients Dependent Variable: SA

Coefficients Dependent Variable: SA						
	Entire Flight		Easy Task		Difficult Task	
	Standardized Coefficients	Correlations	Standardized Coefficients	Correlations	Standardized Coefficients	Correlations
Visual Ability	β	Part	β	Part	β	Part
V_a	-0.057	-0.051	-0.229	-0.186	-0.460	-0.375
V_p	-0.606	-0.494	+0.062	+0.055	-0.277	-0.248
V_{swm}	-0.334	-0.26	-0.530	-0.413	-0.055	-0.042

Table 14 illustrates the β-standardized coefficient and Part-correlation, for V_a, V_p, and V_{swm} as predictors for SA for the Entire Flight, during Easy Task, and Difficult Task.

For the 3-way factorial ANOVA, for the overall sortie V_p [$F(2, 11) = 57.875$, $p = .017$], however, there were no significant effects between Vp, Va, and or Vswm (see Table 11). This shows that V_p performed the most important role. Additionally, for the overall sortie V_a [$F(2, 11) = 17.729$, $p = .053$], even though not statistically significant, it illustrates that V_a played a key role for the overall sortie even though subordinate to V_p. It should also be noted that V_p and V_{swm} had although not a significant interaction, were interacting together more so than any other combination Vp * Vswm [$F(1, 11) = 4.160$, $p = .178$]. This is in-line with the multiple regression analyses and modeling that was also performed for the overall sortie as well, in addition to the varied task difficulty results (Easy versus Difficult).

Furthermore, the tests were statistically significant for the predictor V_p, as task difficulty was varied, $F(2,11) = 12.125$, $p = .003$. Post-hoc comparisons using the Scheffe test indicated that pilots with high V_p scores had reliably higher SA scores than pilots who had low V_p scores (p = 0.006). However, pilots with medium V_p scores had SA scores that did not significantly differ from the high or low V_p scores. Taken together, these results suggest that high levels of V_p do have an effect on SA, as do low scores. The tests were statistically significant for the predictor V_a, during demanding levels of task difficulty, $F(2,11) = 5.749$, $p = .025$. Post-hoc comparisons using the Scheffe test indicated that pilots with high V_a scores had reliably higher SA scores than pilots who had low V_a scores (p = 0.009). However, pilots with medium V_a scores had SA scores that did not significantly differ from the high or low V_a scores. Taken together, these results suggest that high levels of V_a do have an effect on SA, as do low scores. Furthermore, the tests were statistically significant for the predictor V_{swm}, during easy levels of task difficulty, $F(2,11) = 8.397$, $p = .009$. Post-hoc comparisons using the Scheffe test indicated that pilots with high V_{swm} scores had reliably higher SA scores than pilots who had low V_{swm} scores (p = 0.007). However, pilots with medium V_{swm} scores had SA scores that did not significantly differ from the high or low V_{swm} scores. Taken together, these results suggest that high levels of V_{swm} do have an effect on SA, as do low scores.

It was discovered that for this research that placing visual abilities (a ratio level variable) into 3-bins as a function of Z-score in order to categorize them as Low, Medium, and High (a nominal variable), that while reducing nuisance error, created a small loss of fidelity. High accuracy was needed in order to discover the exact contributions, relationships, and predictability of these three neurocognitive abilities V_a, V_p, and V_{swm}. Hence, therefore, in order to maintain precise granularity, multiple regression within factors and repeated measures analysis, and the Pearson correlation were additionally utilized for hypothesis testing and model generation. Allowing the ecological validity and exactitude of this study to be maximized.

Testing of Hypotheses

The following section is an investigation of the study research questions and hypotheses through ANOVA tests to test the null hypotheses. Correlations and multiple regressions were computed in the design analyses to support the testing of the hypotheses. The results are presented along with the ANOVA tests for each hypothesis to determine the significance between the mean scores. The research questions and hypotheses were focused on situation awareness predictor variables. The Pearson correlation results are reported in Table 12 for the independent variables to determine the relationships with situation awareness scores. In addition, regressions were conducted to provide statistical tests in support of hypotheses 1, 2, and 3. Multiple regression analyses were computed to determine the contributions of visual attentiveness, visual perceptiveness, and visual spatial working memory to situation awareness. The three research questions and hypotheses of the relationships and predictors of situation awareness are addressed through the data analyses and results presented below.

This section contains the results for the research questions and hypotheses:

Q1. Under varying task difficulty, are there statistically significant effects of subject inherent visual attentiveness on situation awareness?

H1$_0$. Under varying task difficulty, there will be no statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H1$_a$. Under varying task difficulty, there will be statistically significant effects of inherent visual attentiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

For Q1, the null hypothesis was rejected. The tests were statistically significant for the predictor visual ability V_a as task difficulty was varied; $F(2,11) = 5.749$, $p < 0.025$. In addition, multiple regression analyses revealed that for this model ($R^2 = 0.753$, p = .008). During high task difficulty V_a ($r[12] = -0.583$, $p = .023$) had the strongest relationship. Post-Hoc tests revealed a Cohen's $f^2 = 3.05$ yielding statistical power to be 0.98.

Q2. Under varying task difficulty, are there statistically significant effects of subject inherent visual perceptiveness on situation awareness?

H2$_0$. Under varying task difficulty, there will be no statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

H2$_a$. Under varying task difficulty, there will be statistically significant effects of inherent visual perceptiveness, (as measured by the Integrated Visual and Auditory Continuous Performance Test Plus [IVA+]; Brain Train, 2010), on resulting situation awareness.

For Q2, the null hypothesis was rejected. The tests were statistically significant for the predictor visual abilities V_p, as task difficulty was varied; $F(2,11) = 12.125$, $p = .003$. In addition, multiple regression analyses revealed that for this model ($R^2 = 0.753$, p = .008; $Predicted\ Z_{SA} = 11.646 - 0.606Z_{Vp} - 0.057Z_{Va} - 0.334Z_{Vswm}$). Moreover, the Pearson correlation results indicated that V_p (r[12] = -0.816, p = .001) had the strongest relationship of the three neurocognitive factors for the overall sortie. Post-Hoc tests revealed a Cohen's $f^2 = 3.05$ yielding statistical power to be 0.98.

Q3. Under varying task difficulty, are there statistically significant effects of subject inherent visual spatial working memory on situation awareness?

$H3_0$. Under varying task difficulty, there will be no statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

$H3_a$. There will be statistically significant effects of Visuospatial Working Memory Test results (AFRL, 2009), on resulting situation awareness.

For Q3, the null hypothesis was rejected. The tests were statistically significant for the predictor visual ability V_{swm} as task difficulty was varied; $F(2,11) = 8.397$, $p = .009$. In addition, multiple regression analyses revealed that for this model ($R^2 = 0.753$, p = .008). Post-Hoc tests showed a Cohen's $f^2 = 3.05$ yielding Statistical power to be 0.98. Interestingly during low task difficulty V_{swm} (r[12] = -0.634, p = .013) had the strongest relationship.

Evaluation of Findings

This study was an assessment of the extent to which visual attentiveness, visual perceptiveness, and visuospatial working memory had an effect and relationship with SA. Based on the findings presented in this study, it is evident that these cognitive abilities are significant predictors of SA, explaining in total 75% of the variance in SA. The findings supported the first alternative hypothesis (H_{1a}) by demonstrating a statistically significant effect and relationship between visual attentiveness and SA. Furthermore, the results supported the second alternative hypothesis (H_{2a}) in that there was a statistically significant effect and relationship between visual perceptiveness and SA, and in relation to the third alternative hypothesis (H_{3a}) there was a statistically significant effect and relationship between Visual Spatial Working Memory and SA. The correlation and regression analyses results provide further strong support for a statistically significant relationship between these predictors and SA.

Visual attentiveness, visual perceptiveness, and visuospatial working memory were predictors of SA. Visual Perceptiveness (V_p) is the ability to have perceptivity, to be insightful, and to have discernment - the ability to perceive that which is obscured. This variable is derived from visual Prudence, Consistency, and Stamina scales (Sandford &Turner, 2009). The study results indicated that V_p ($r[12] = -0.816$, $p = .001$) had the strongest relationship of the three neurocognitive factors for the overall sortie. This indicates that visual perceptiveness is the most important trait for situation awareness (SA). During a typical sortie, task difficulty will range from low to high and in-between, therefore for a typical sortie V_p is the most important and most influential factor, variable, and predictor overall of SA.

Prudence is a measure of impulsivity and response inhibition. A higher Prudence score is indicative of traits consisting of being circumspective and mindful. The IVA+ measures three types of *commission* errors -- impulsivity, propensity, and mode shift to obtain the Prudence score = 100 - ((Number of Prudence visual errors / 65) * 100, Sandford &Turner, 2009). Descriptors of Prudence are Focused Attention and Selective Attention. Consistency, the second major factor for V_p, is sustaining a reliable effort and staying on task. Therefore, Consistency as a measure of the reliability and variability of response times = (Quartile 1 visual reaction time / Quartile 3 visual reaction time * 100, Sandford &Turner, 2009). The third major factor is Stamina, and this is being able to maintain speed of mental processing. Stamina compares the mean reaction times of correct responses during the first 200 trials to the last 200 trials and equals = ((Mean visual reaction time (MVRT) of sets 1+2) / (MVRT of sets 4+5)) * 100 (Sandford &Turner, 2009). The V_p score was a composite quotient score that was derived from these three categories by means of the IVA + software.

Visual Attentiveness (V_a) is the ability to concentrate and be devoted, to be diligent and detailed, alert, watchful, and responsive. This variable is derived from visual Vigilance, Focus, and Speed scales (Sandford &Turner, 2009). The study results indicated that V_a ($r[12] = -0.583$, $p = .023$) had the strongest relationship of the three neurocognitive factors during high task difficulty. This indicates that visual attentiveness is the most important trait during high task difficulty for situation awareness (SA). Consequently, during a phase when task difficulty is high, V_a will rise to the top as the most important and most influential factor, variable, and predictor of SA.

Vigilance is a measure of inattention as evidenced by two different types of errors of omission. One error is defined as a failure to respond to a target and the other is defined as a non-response to a target immediately after a foil has been presented during frequent blocks. A higher Vigilance score is indicative of traits consisting of being intense and accurately responsive. The IVA+ V_a = 100 - ((Number of Vigilance visual errors / 45) * 100) (Sandford &Turner, 2009). To be vigilant, an individual must maintain and direct attentional effort to classify each stimuli as either a target or foil and then make the appropriate response (Sandford &Turner, 2009). Focus is the second major factor for V_a and reflects the variance in reaction time speed measuring the ability to sustain and maintain attention. Therefore, Focus = 1 - (SD of visual reaction times / Mean visual reaction time)) * 100 (Sandford &Turner, 2009). The third major factor is Speed reflects the average reaction time for correct trials throughout the test, thus Speed measures discriminatory mental processing speed. Speed equals = Mean visual reaction time in milliseconds for all correct trials (Sandford &Turner, 2009). The V_a score was a composite quotient score that was derived from these three categories by means of the IVA + software.

Visuospatial Working Memory (V_{swm}) is the ability to have the part of memory that is responsible for recording and logging information about one's spatial environment including spatial orientation of one-self, coupled with actively holding multiple pieces of transitory spatial information in the mind, where it can be manipulated. This variable is derived from the Visuospatial Working Memory N-back test (AFRL, 2009; Gevins & Cutillo, 1993; Sohn, & Doane, 1997, 2000, 2003). The study results indicated that V_{swm} ($r[12] = -0.634$, $p = .013$) had the strongest relationship of the three neurocognitive factors during low task difficulty. This indicates that visuospatial working memory (V_{swm}) is the most important trait during low task difficulty for situation awareness (SA). Consequently, during a phase when task difficulty is low, V_{swm} will rise to the top as the most important and most influential factor, variable, and predictor of SA.

It is noteworthy that for the overall entire flight V_{swm} was the second most influential factor and predictor of SA (see Table 14). Further studies should be conducted to validate these neurocognitive predictors of SA within diverse populations that take into consideration age, experience, and education level. Even with the limitations of the study, the findings can be used as a basis for examining other potential predictors while enhancing the current TMSA; additionally this study improved the definition of SA. The following chapter presents and discusses the implications and recommendations that emerged from this study.

Chapter 5: Implications, Recommendations, and Conclusions

This chapter will cover a brief review of the problem statement, purpose, method, limitations, and ethical dimensions. Implications will be discussed as well as theoretical and practical significance. This research will be summarized involving questions and hypothesis in order to draw logical conclusions. Additionally the results will be put back into context by describing how the results respond to the study problem, fit with the purpose, demonstrate the significance, and contribute to the existing literature described in Chapter 2. Finally, this chapter will conclude with recommendations and conclusions (also, see Appendix B).

Cognitive situation awareness has been a topic of exploration in the behavioral sciences. Situation awareness may be modestly defined as the human ability to perceive and comprehend the environment, and use that information to undertake a task (Endsley, 1995a). Previous exploration suggested that cognitive situation awareness is critical to a wide range of human performance, but most notably in aviation (Bailey, Shelton, & Arthur, 2011; Cass, 2011; Crawford & Neal, 2006; Salmon, et al., 2010; Kim, 2009; Wickens, 2008). In aviation from 1980 to 2007, 983 accidents occurred worldwide involving aircraft without an installed Head Up Display (HUD) (Flight Safety Foundation, 2009). A recent review of this accident data revealed that the majority were due to reduced cognitive situation awareness of the aviator, combined with limited visibility, and operations into austere locations (Arthur, Prinzel, Williams, & Kramer, 2006; Bulkley, Dyre, Lew, & Caufield, 2009; Flight Safety Foundation, 2009; NTSB, 2009). Despite the importance of situation awareness in human performance, in the past there has been no consensus on predictors or antecedents (it has been unpredictable), an area that tended to be elusive and theoretically vague (Cass, 2011; Douglas, Aleva, & Havig, 2007; Dekker & Hollnagel, 2004; Gorman, Cooke, & Winner, 2006; Harbour, Hudson, & Zehner, 2012; Jodlowski, 2008; Rousseau, Tremblay, & Breton, 2004; Sulistyawati, Wickens, & Chui, 2011; Wickens, 2002, 2008). A better understanding of the antecedents of situation awareness will advance the theory of how situation awareness is formed and maintained, as well as produce improvements that could apply to any task involving visual displays, information integration, and mental training.

The focus of this project was to conduct neuroergonomic empirical studies that identified the primary abilities that are essential antecedents of situation awareness (causing it to be predictable). As the scientific concept of situation awareness must be defined with respect to a particular task, this project focused on the complex multitask of piloting a military aircraft. To reduce the confounds of variance in pilot populations and aircraft types, the scope was confined to the USAF Air National Guard population who fly tactical airlift in north central Ohio with emphasis on task saturating phases of flight, where situation awareness was especially stressed due to increased mental workload (FSF, 2009). It should enhance behavioral science in this area by shedding light on the significance of visual attention and visuospatial working memory as the antecedents or predictors of cognitive situation awareness. In doing so, this work answered the literature's exigent call to advance cognitive situation awareness theory (Endsley, 2012; Gutzwiller & Clegg, 2012; Harbour & Hudson, 2013; Sulistyawati, Wickens, & Chui, 2011; Vidulich & Tsang, 2012; Wickens & McCarley, 2008), while addressing a problem of real-world significance (Bulkley, Dyre, Lew, & Caufield, 2009; Flight Safety Foundation, 2009; NTSB, 2009; Wickens & McCarley, 2008).

There was limited literature and research regarding neurocognitive predictors of situation awareness and display usability with USAF pilots while performing complex tasks (Douglas, Aleva, & Havig, 2007; Ellis & Levy, 2009; Endsley, 2012; Gillan et al., 2009; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Sulistyawati, Wickens, & Chui, 2011; Vidulich & Tsang, 2012; Wickens, 2008; Wickens & McCarley, 2008; Tirre & Gugerty, 1999, 2000). Visual processing was categorized as static and dynamic (Proctor & Vu, 2010), and operationalized as visual attentiveness and perceptiveness, integrated with visuospatial memory (Brain Train, 2010; Christensen et al., 2013; Corbett & Constantine, 2007; Endsley, 2012; Gugerty, in press; Sandford, Fine, & Goldman, 1995; Sandford & Turner, 1994; Vidulich & Tsang, 2012; Wickens & McCarley, 2008).

The problem that was addressed by this research was that despite the scientific exigency there were no precise and predictive nexuses for current theories of situation awareness and concrete quantifiable cognitive and perceptual processes (Douglas, Aleva, & Havig, 2007; Ellis & Levy, 2009; Elliott et al., 2009; Endsley, 2012; Gillan et al., 2009; Gugerty, in press; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Lau, Jamieson, & Skranning, 2013; Proctor & Vu, 2010; Sulistyawati, Wickens, & Chui, 2011; Vidulich & Tsang, 2012; Wickens, 2008; Wickens & McCarley, 2008; Tirre & Gugerty, 1999, 2000). After years of work since Endsley's Theoretical Model of Situation Awareness (TMSA, 1995a) was first published, current models of situation awareness remained conceptual models that provided little specificity with regards to the neurocognitive processes that are necessary for the formation and maintenance of situation awareness

(Gillan et al., 2009; Lau, Jamieson, & Skranning, 2013; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). While the TMSA recognized perception as a critical first step, there were no specific or quantitative links between perceptual abilities and situation awareness; nor did subsequent work prior to this dissertation been able to clarify the issue, e.g. the effects of visual ability on the level of situation awareness (Jen-li, Ruey-Yun, & Ching-Jung, 2013; Jones, Connors, & Endsley, 2011; Vidulich & Tsang, 2012; Sulistyawati, Wickens, & Chui, 2011). Needed theoretical advancement in this area was hampered by a lack of specific, testable predictions regarding plausible component processes; there has been little theoretical progress due to this (Douglas, Aleva, & Havig, 2007; Endsley, 2012; Gutzwiller & Clegg, 2012; Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens, 2008; Sulistyawati, Wickens, & Chui, 2011).

The seminal research done by Tirre and Gugerty (1999, 2000), Wickens and McCarley (2008), Elliott et al., (2009), Jen-li, et al., (2013), and Gugerty, (in press) found that visual processing (Proctor & Vu, 2010), was involved in situation awareness (Vidulich & Tsang, 2012). However, the specific neurocognitive component processes had not been explored in detail prior to this dissertation (Gutzwiller & Clegg, 2012; Gugerty, in press; Harbour et al., 2012; Jen-li et al., 2013; Jones & Endsley, 2012; Sulistyawati et al., 2011; Vidulich & Tsang, 2012). Therefore, this work tested explicit hypotheses regarding specific abilities that were found to contribute to situation awareness making it predictable. The results of this study fills in a key and critical gap in the TMSA, and in so doing enables both theoretical refinement and practical applications such as improved procedures, training for pilots, and display design that improves flight safety, this problem was answered and the solution discovered.

Purpose

The primary objective of this quasi-experimental quantitative study was to test the predictive value of these particular candidate visuo-cognitive abilities: (a) Visual Attentiveness, consisting of Vigilance, Focus, and Speed, (b) Visual Perceptiveness, consisting of Prudence, Consistency, and Stamina, and (c) Visuospatial Working Memory, which consisted of Working Memory that is stored in the visuospatial sketchpad in the mind, as predictors of situation awareness, e.g. the effects of visual ability on the level of situation awareness. Therefore, this project tested the predictive value of these variables as factors in a particular task to be performed and the eventual outcome of situation awareness. As Pavlov, Watson, and Skinner performed field experiments in order to contribute to psychological theory (Cervone & Pervin, 2007), a field research in the paradigm of neuroergonomics (Parasuraman, Christensen, & Grafton, 2012) employing quasi-experimental repeated-measures (within-participants), was conducted for this study. Further inquiry involving visual cues clarified the role of these abilities in order to make theory-driven predictions for situation awareness (Harbour et al., 2012; Vidulich & Tsang, 2012; Wickens & McCarley, 2008). Statistical analyses of the data indicated that this purpose was achieved.

Method

The primary purpose of this quasi-experimental quantitative study was to test visual perceptiveness, attentiveness, and spatial working memory as predictors of situation awareness. In order to maximize ecological validity and minimize nuisance variance due to heterogeneous participants, this project focused on the controlled assessment of the visuocognitive abilities of Air National Guard pilots, with actual piloting as an entirely real task suitable for measuring resulting situation awareness.

This was the most practical, effective, and realistic method to perform the research that addresses the problem and the purpose. As an example alternative approach, a completely laboratory based study utilizing the typical convenience sample of college undergraduates could be accomplished; however, one would expect significant individual differences as well as serious concerns about the measurement of situation awareness outside any meaningful task context. If this work is wholly successful, it will result in significant elaboration of theoretical models of situation awareness as well as enabling and focusing efforts to improve situation awareness.

In order to induce meaningful variation in the outcome measures of situation awareness, task difficulty in the flight task was manipulated between two levels, an easy or low difficulty level associated with efficient and easy-to-use information displays and a hard or high difficulty level associated with ineffective information displays. Each pilot was assessed for the three candidate visual abilities (attentiveness, perceptiveness, and visuospatial working memory). This approach resulted in a quasi-experimental design that made use of repeated measures comparisons (Cozby, 2001; see Table 3) four times per subject, in order to achieve required statistical power. The experiment was organized in much the same manner as a strict experimental design however due the operational realism involved it lacked complete randomness (Creswell, 2009; de Vaus, 2001; Moore, 2007). This lack of randomness was recognized, and was accounted for during the entire experimental process (Trochim & Donnelly, 2008). This tradeoff between experimental control and ecological validity, while a compromise, should improve the validity, generalizability, and significance of this study (Alasuutari, Bickman, & Brannen, 2008).

Correlation and causation analyses utilize mathematical tools such as the Analysis of Variance (ANOVA) to study effects on one dependent variable by more than one independent variable, along with multiple regression analysis and the Pearson correlation (Grim & Yarnold, 2006). The within-subjects and factors repeated-measures ANOVA, moreover with multiple regression analysis were used to measure the main effects of the independent variables (three visual abilities) the interactions among the independent variables, the importance of the dependent variable (situation awareness), and the strength of association between these variables.

Limitations

Some of the pre-existing factors such as the subject pilot's previous experience using HUDs and his or her level of piloting skills were not taken into account. In addition, there are an untold number of possible outside influences that may affect the results, such as sleep quality, family/emotional disturbance, diet, etc. (Cervone & Pervin, 2007). There was not complete randomness. Even with these disadvantages, because the shortcomings were recognized throughout this study, and repeated measures were taken, the results should still be viable and valuable (Creswell, 2009; de Vaus, 2001; Trochim & Donnelly, 2008). The quasi-experimental design was the best choice for this study and was very useful in generating results for trends and relationships between variables (Creswell, 2009; de Vaus, 2001; Moore, 2007; Trochim & Donnelly, 2008). The experiment proceeded with a variable or variables being compared between different IDs used (HDD and HUD) and within group over a period of time. The quasi-experimental design allowed for statistical analysis to take place, without extensive pre-screening and randomization needed to be undertaken, reducing the time and resources required for experimentation (as this study is a dissertation therefore there are limitations to funds and time to complete).

Ethical Dimensions

The subjects flew the aircraft with an associated very low and minimal risk level. Serious thought was devoted to these flights, the possible risks involved, and possible mitigations for those risks such as a "knock it off" call by anyone of the subjects or the researcher. The study sought to maximize realism in order to develop more robust answers and theory—with pilots flying the actual aircraft, rather than using simulators. The risk was discovered to be small or minimal during both the NCU IRB (see Appendix B) and USAF IRB (see Appendix C). This study was conducted with an AFRL IRB and NCU IRB approval; participants completed comprehensive written informed consent, and all appropriate USAF boards were performed (see Appendices' B and C).

The rights, privacy, responsibilities, and safety of the researcher and subjects was strictly respected and adhered to at all times for this study (Creswell, 2009).

Implications: Theoretical and Practical Significance

This study provides significance to the scientific field of psychology that is both theoretical and practical. Theory in psychology aims to explain or describe at some level the operation or process of the brain or mind from either or a combination of a performance, an emotion, a cognitive, and or a behavior perspective (Carlson, 2010; Cervone & Pervin, 2007; Matlin, 2008). The term theory does not have an absolute single one-size fits all definition (Benthem, 2007; Harlow, 2009). Psychology contains a range of differing ideals that define theory and a broad assortment of uses of the term "theory", some that are very scientific and some that are not (Harlow, 2009).

Theory

Psychology, like physics is the study of a vast and confusing phenomena to comprehend and explain, the human mind versus the cosmos at both the macro and micro level contain similarity. Theory in cognitive psychology lends itself to being mathematically analyzable. Cognitive psychology typically is human performance based. Viewing theory using parsimonious taxonomies towards differentiation, evaluation, and formulation, enriches the perspective of theory, therefore providing the catalyst to create. In the view of three scholars, Lynham, DiMaggio, and Heinen, theory can be envisaged in many different ways. There exist three fundamental views of what constitutes theory based on what DiMaggio (1995) surmises as, "theory as covering laws, theory as enlightenment, and theory as narrative" (p. 391). Citing Habermas's three-perspective classification, Lynham (2002) indicated these three, partition theory as, empirical-analytical, interpretive, and critical (p. 225). Parsimoniously categorizing theories further, according to Heinen (1985) in reality there are only two classes: concatenated theory and hierarchical theory (pp. 417-418). After, much review this learner and candidate believes that the three views expressed in DiMaggio's (1995) work capture and encompass most current and varying scholarly views of theory, today, and for the foreseeable future. Two fundamental aspects will be covered as they are apropos for this study and the TMSA.

Theory as Covering Laws. This is the *positivist* view of theory, e.g. the Hick-Hyman Law. Sutton and Staw (1995) considered this theory as being narrow-minded and too robotic. Sutton and Staw (1995) discarded the ideas that theory must be based on: a) rejecting the null hypothesis, and b) only items in the world that can be quantifiable and measured exactly. On the contrary, most social scientists and physicist would view *theory as law* as being proper, and in turn view Sutton and Staw as being extremists (DiMaggio, 1995). DiMaggio (1995) shared the same opinion with Sutton and Staw (1995), however. This anti-positivist view regards *theory as law* as being too absorbed into the Pearson product squared (R^2) as the "judge" for good theory and that positivist focus too much on clarifying variance rather than regularities (DiMaggio, 1995). On the other hand, Friedman (1953) viewed the (R^2) notion as being correct and that *theory as law* is truth, therefore providing if the (R^2) value is high it is then good theory, Sutton and Staw argue it only provides the "what", not the "how" or "why". One could take the view that *theory as law* to be mostly deductive in nature by using data to test theory (Eisenhardt & Graebner, 2007; Goel & Dolan, 2004; Sternberg, 2009). Based on Einstein's (1916) Relative theory one could infer that Einstein would view good theory to be *theory as law* whereas, Quantum theorist may view *theory of enlightenment* as good theory, instead, however, this candidate and researcher views them both as good theory when combined. The TMSA in its current state is not *theory as law* but is *theory as narrative.*

Theory as Narrative. This is the *functionalist* view of theory. DiMaggio (1995), considers this theory as being a mix of *theory as law* and *theory as enlightenment, theory as narrative* combines, narrative accounts of processes along with importance on empirical tests of feasibility**.** Collins (1981) has an austere form of this view and refers to it as *micro-translation* whereas theory does contain a hypothesis, but it merely specifies the consistencies among variables to include relationships, while being simultaneously tied in with plausible accounts observing and predicting how the actual interactions and associations are produced. The approach of Farrao (1989) for theory is similar but yet more aggressive in that a *baseline generator* in the form of a model replicates human behavior based on a set of governing principles. Through computer simulation, utilizing this model observing the output and distributions will culminate into the conclusions. DiMaggio, Sutton and Straw view, this view of theory being *narrative* in much the same way (Dimaggio, 1995; Sutton & Straw, 1985), this opinion of the narrative approach in respect to theory is in-between the views of Fararo and Collins. That is, *theory as narrative* is a more equal mix of *theory as law* and *theory as enlightenment,* whereas Fararo leans heavier towards *theory as law* and Collins leans heavier towards *theory as enlightenment*. The TMSA in its current state is *theory as narrative.*

Scientific Theory. Rychlak (1968) as described in Gelso (2006), and Ellis and Levy (2009), indicate four primary functions underpin theory: (a) descriptive, (b) delimiting, (c) generative, and (d) integrative. Narrative answers the *why*, delimiting bounds, generative stimulates new research adding to the body of knowledge, and integrative, pursues to make what appears to be dissimilar similar giving a sound connected view. Three types of theory that are apropos to psychology (Bachman & Schutt , 2007; Gay & Weaver, 2011; Locke, 2007): (a) hypothetico-deductive theory (Rynes & Gephart, 2004), (b) inductive-synthesis theory (Wacker, 1998, 2008), and (c) critical theory (Torraco, 2002). Hypothetico-deductive will be expressed here.

Hypothetico-deductive theory is very apropos to this study. It is based on the quantitative research method using operational constructs and variables (Rynes &

Gephart, 2004). It involves realism, utilizing measured data for hypothesis testing. This type of theory yields theoretical models, laws, and universal truths.

In addition, the type of psychology theory is very much dependent, upon the topic the research is examining, which then also influences the type method, quantitative or qualitative used (Trochim & Donnelly, 2008). A theory could be a scientific law or related laws such as Newton's Laws of Motion (Griffith, 2007) which is based on the quantitative method, or a set of constructs for understanding phenomena such as the individual's basis for fear of crime in the United Kingdom grounded in the qualitative method (Harlow, 2009).

Quantitative Method (Hypothetico-Deductive). This research method depends far less on observations, interviews, focus groups, and case studies as found in the qualitative method where theory could evolve and immerge. The quantitative method relies far more on the formulation of a hypothesis at the onset based on previous research, next an experiment or series of experiments is or are accomplished, followed by the statistical analysis of the data collected to test the hypothesis in order to answer the research questions. For theory development from the quantitative method, the foremost elements in research are the hypothesis, what is varied (independent variable/s) along with what is measured (the dependent variable/s) in order to test the hypothesis (Harbour, 2006; Harbour, 2007; Harbour, 2011; Moore, 2007). This dissertation employed this method.

The literature supports the ideology that theory is the return on investment or payoff from investing in or the performing of scholarly research (Gelso, 2006); in the case of the author's dissertation, it would be theory in psychology, cognitive neuroscience, engineering, aviation, and human factors, combined. The Theoretical Model of Situation Awareness (TMSA) (Endsley, 1995b) is *theory as narrative* for it combines narrative accounts of processes along with emphasis on empirical tests of feasibility. Endsley's framework is grounded in hierarchical levels of SA and is based on information processing. Level 1 SA contains the perception and processing of cues. An example could be perceiving the environment and a display yielding spatial awareness (Endsley, 2012; Wickens, 2007; Wickens et al., 2008). Level 2 SA is the comprehension of the current situation by utilizing the information gained from Level 1 SA perceptions combined with individual background knowledge, thereby creating a situation model (Endsley, 2000a, 1995a; Wickens, 2007). Level 3 SA is the utilization of the situation model to project and predict the future state (Endsley, 1995a, 2000b; Sulistyawati, Wickens, & Chui, 2011; Wickens, 2007). Endsley's (1995a; 2002a) view of SA is often utilized as the basis for research in areas, including system displays and military operations (Eid, Johnsen, & Brun, 2004; Sulistyawati, Wickens, & Chui, 2011). SA is difficult and challenging to quantify, it is viewed as a complicated tangible, that exists and necessitates an acute sense for visual signals (Endsley, 2012; Dekker & Hollnagel, 2004; Elliott, et al., 2009; Jodlowski, 2008; Parasuraman, Sheridan, & Wickens, 2008) feeding on the perception of the elements in one's world within the dimensions of space and time (Endsley, 2012). However, in argument there were at least 34 different and or varying definitions of SA with little consensus in the scientific community (Cass, 2011; Dekker & Hollnagel, 2004; Jodlowski, 2008; Rousseau, et al., 2004; Wickens, 2008) and the same existed for the exact composition of SA to include its predictors (Blandford & Wong, 2004; Elliott, et. al., 2009; Gorman, et al., 2006; Jodlowski, 2008; Rousseau, et.

al., 2004). To complicate matters further, there are at least three different theories for SA (Stanton, Chambers, & Piggott, 2001), the *TMSA – a three level model* that is a cognitive theory that uses an information processing approach (Endsley, 1995a), the *theory of activity model* to describe SA (Bedny & Meister, 1999), and the *perceptual cycle theory model* that is an ecological approach (Niesser, 1976; Smith & Hancock, 1995), these theories diverge in their foundational psychological methodology (Salmon, et al., 2008).

This fuels the debate on how to best measure SA even though at hand are a plethora of approaches to assessing SA and the copious theoretical debate that hinges over whether SA refers to the *process* of gaining awareness, or the *product* of it, or a combination of the two (Salmon, et al. 2008). The continuing debates over SA illustrate the need to refine the theory (Dekker & Hollnagel, 2004; Patrick & Morgan, 2009; Wickens, 2008). Consequently, there simply was no established *theory as law* of SA, and therefore, no specific mathematical equation or variable relationships that include SA predictors. The TMSA utilizes an information processing approach, not an activity approach, nor an ecological approach (Stanton, et al., 2001) it is a functional model for assessing distinct levels of insight in a realistic fashion. Further controversy existed within the TMSA, Endsley's theory emphasizes perception and comprehension of the environment amid projection into the future however it did not contain enough granularity or accuracy in the area of human perception (Elliott, et. al., 2009; Gorman, et al., 2006; Jodlowski, 2008; Stanton, et al., 2001; Wickens, 2008). The TMSA did not emphasize reflective relationships between mental models and knowledge of the present system. SA may be a unique psychological construct on its own (Bell & Lyon, 2000; Moray, 2004).

SA is a vital paradigm that continues to provoke controversy (Wickens, 2008). What is needed, but missing from Endsley's theory of SA (2012) is an approach for predicting the pilot's ability, to perceive the display cues while using the display in order to operate an aircraft or UAV (multi-tasking), predicting Level 1 SA remained a needed challenge (Harbour, et al. 2012; Wickens & McCarley, 2008). Finally, as any significant concept should, SA has spawned some degree of rigorous academic debate (Dekker & Hollnagel, 2004; Dekker & Woods, 2002; Patrick & Morgan, 2009; Wickens, 2008).

An understanding of the visual processing factor was incomplete and research to refine measurement of these abilities needed to be accomplished. Elliot, Wickens, Parasuraman, Christensen, and many others have been performing research to solve this unknown (Endsley, 2012; Vidulich & Tsang, 2012). While filling in a gap in the TMSA specifically at Level I, this dissertation study provides *Theory as Law* to the existing *Theory as Narrative* TMSA with the following mathematical equation:

$$Predicted\ Z_{SA} = 11.646 - 0.606Z_{Vp} - 0.057Z_{Va} - 0.334Z_{Vswm}.$$

This research was successful by providing continuity to the breach in the TMSA and offers an *Enhanced-TMSA* by providing the specific measurable neurocognitive attributes that are required to feed Level 1 SA – perception, allowing SA to be quantifiably predictable. This is a psychological theory that could be appropriate in many different domains involving human behavior.

There is a relationship between the results of this dissertation and current research in computational intelligence, precisely the QUEST approach (Rogers, 2009). The main objective of QUEST is to develop a general-purpose computational intelligence system that captures the advantageous engineering aspects of qualia based solutions. Ultimately, a QUEST system should have the ability to detect, extricate, and portray entities in the environment, to include a representation of its self and possess self-awareness. In a sense, then, QUEST is working towards a Theory of Consciousness Awareness (Rogers, 2014). In so doing, QUEST is utilizing an emerging theory in psychology referred to as Dual-process or Dual-system theory (Evans & Stanovich, 2013). Dual-process theory is premised on the idea that human behavior and decision-making involves autonomous processes (Type 1) that produce default responses involving an implicit process unless interceded upon by distinctive higher order reasoning processes (Type 2). Type 2, on the other hand involves an explicit process and burdens working memory. Typical correlates associated with Type 1 are automatic, non-consciousness, and basic. Type 2 is typically associated with: controlled, consciousness, and complex (see Figure 14). With the uncontrolled nature of in-flight events, one may assume that pilots had to engage both types of processing on any given flight. The neurocognitive predictors may reflect efficiencies in Type 1 processing that translate to a reduced need for Type 2 and attendant lower workload and higher SA. Stated differently, pilots with stronger perceptual and attentive capabilities may need to engage the effortful Type 2 system less, thus preserving spare capacity for maintaining SA.

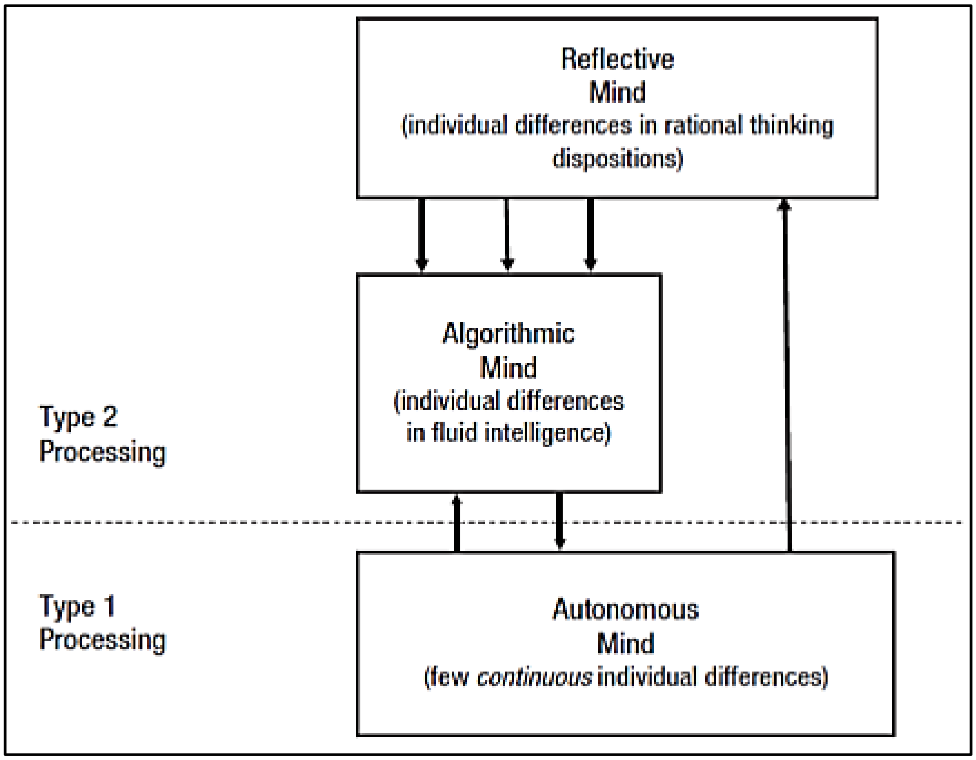

Figure 14. Dual Processing Theory involving both Type 1 and Type 2 processes (Evans & Stanovich, 2013).

During the 24 flights, there were unexpected queries (UQ) encountered by the pilot as well as expected queries (EQ) based on environmental stimuli. During the sorties both UQ and EQ were occurring. However, since it was not central to this dissertation's problem statement and purpose it was not ferreted out as to whether or not any differences in UQ and EQ for situation awareness and cognitive workload outcome existed. Consequently, in working towards a Theory of Consciousness Awareness this will need to occur in future research based on environmental stimuli (Rogers, 2014).

Practical Application

The most useful psychological theory is one that is systematic, testable, and comprehensive with the ultimate goal of being able to construct the theory into one of the tools to be applied by the psychologist or engineer in practical application to better understand, improve, and predict human thought and behavior (Santrock, 2008). Basic research expands science and or creates new theory, and is a goal of the Ph.D. dissertation. The product of which is a significant advancement transversely on a broad front of knowledge expansion of natural and social phenomena (Jain, Triandis, & Weick, 2010). To obtain a deepened comprehension of the subject matter under study, in order to increase knowledge and theory in the science or field without necessarily a particular application in mind, is the main object of basic research (Jackson, 2009; Jain, et al., 2010). On the other hand, applied research uses the very principles that basic research discovers towards practical application (Jackson, 2009). A practical implementation is focused on finding the means by which a specific, recognized need may or can be met (Jain, et al., 2010). Basic research discovers the theories in science and potentially finds what theory maybe better suited than another to solve a problem. Whereas the results of applied research which could be a practical application using that discovered theory in science and applying it to a specific issue in order to make, and or build, and or apply it for something new to full-fill a need, treatment plan, or safety. Basic research, applied research, and practical application are equally important because many treatments and procedures that have been developed to help humans result from research and implementation (Jackson, 2009). The *Enhanced – TMSA* can be applied by utilizing the SEEV Model improving SA, and or employing cognitive training to enhance these individual neurocognitive factors resulting in improved flight safety.

How the *Enhanced - TMSA* Can Be Applied. Applying the *Enhanced - TMSA* to cockpit design, pilot training, and pilot selection could offer-up the quickest benefits today. The practical need is that approach and landing accidents are of concern, especially at austere locations or where the weather creates poor visibility (Arthur, Prinzel, Williams, & Kramer, 2006; Bulkley et. al, 2009). From 1980 to 2007, in commercial aviation 983 accidents occurred, involving multiengine jet aircraft that weighed 12,500 pounds or more with glass cockpits, and were due to causal factors such as reduced SA and increased mental WL of the pilot, combined with limited visibility, and operations into ascetic places (Flight Safety Foundation, 2009). Deficient situation awareness can lead to fatal accidents, in particular the number-one killer in commercial aviation, CFIT (Wickens & McCarley, 2008). It has been reported that if situation awareness could be improved this accident potential could be reduced by 33 to 73 percent, saving lives and an estimated $1 million per commercial and military aircraft over the next 10 years (FSF, 2009; Prinzel & Risser, 2004; Rockwell Collins, 2000).

Based upon leading safety experts' evaluations as derived from information obtained in flight simulators, it is believed that those accidents could have been prevented had an appropriately HUD been installed in the cockpit and SA been improved (Flight Safety Foundation, 2009; Kim, 2009) and this dissertation supports those evaluations. For the practical application designer the *Enhanced-TMSA* would enable optimization by making valuable information more salient, and it can reduce the effort of switching between sources with high bandwidth and likely PRPs. Installing a HUD in every aircraft is the quickest way to achieve this.

With the application of the *Enhanced-TMSA*, aircraft cockpits could be designed to where the location and appearance of symbology on the display more efficiently correspond in both appearance and place with the actual environment in the most efficient prioritized manner (FSF, 2009). Synthetic and enhanced vision HUDs could be designed and installed by using the *Enhanced- TMSA*, and SEEV application derived from MRT (Bulkley et. al, 2009). Additionally, these could be used in NextGen airspace for the planned control of both Unmanned Arial Vehicles (UAVs) and manned aircraft flying in the same airspace simultaneously within close proximity (Gore, et. al, 2009). In automobiles, the applications could be for 3D maps (Wickens & McCarthy, 2008; Cannon, Nguyen, & Regli, 2012) improving safety. These applications could be soundly grounded in the *Enhanced- TMSA*, based on the solid psychological theory presented here and reliable engineering applications (Sarter, 2012). Consequently, the reasoning linking implementation and theory is sound, the particular links being *Selective attention, Task selection, Allocation, Demand, and Multiplicity* (Wickens & McCarthy, 2008). Consequently, moreover computerized cognitive training (CCT) should be considered in order to potentially improve these abilities potentially, as well.

The Study's Impact on the Literature

There was a lack and need for additional psychological theory that is based on the neurocognitive abilities to perceive the visual display's cues, predicting situation awareness and workload (Harbour, et. al., 2012; Kim, 2009; Endsley, 2012; Sulistyawati, et. al., 2011; Vidulich & Tsang, 2012) succinctly quantitatively grounding the TMSA. This was covered and expanded upon further in the Literature Review. This Ph.D. study has made a solid and expansive contribution to the literature in behavioral science by addressing a fundamental gap in cognitive situation awareness theory by way of examining both pilot neurocognitive factors and flight display three-dimensional placement, and how and why they may well affect situation awareness and workload.

Flying modern military aircraft and unmanned aerial vehicles is indeed operating a complex system, performing several tasks at the same time that increase the pilots' mental WL. Accurate mental workload assessment and SA prediction is critical because WL significantly affects human performance, and a better understanding of the available mental capacity (for SA) and WL relationship is vital (Kang, 2008). For instance, up to 82% of highway accidents result from distraction (inattention), and today's workforce see the car as a mobile office (the birth of the "multi-tasking" next generation) (Wickens & McCarley, 2008).

Nineteen quantitative experiments and fifteen research articles have illustrated the need and attempted to discover the detailed links between vision, cognition, predictability, and situation awareness. Over this 15-year period, up to and including current present day, the research has gotten closer, illustrating the continuing need to fill this gap in the TMSA. Additionally, three other theories and or models have links to the TMSA and they are Applied Attention Theory (AAT) (Wickens & McCarley, 2008), Multiple Resource Theory (MRT) (Sarter, 2012), and the Salience Effort Expectancy Value (SEEV) Model (Wickens & McCarley, 2008). Five quantitative experiments and six research articles have shown these to be linked and influenced by the TMSA; consequently, this research benefits those theories as well. This dissertation identified critical variables underlying the formation of situation awareness as well as the relationships among these variables filling this scientific void in theory (Elliott et al, 2009), grounding the TMSA in concrete and quantifiable perception and cognitive processes.

What was known is that situation awareness plays a vital role in dynamic decision-making environments (St. John & Smallman, 2008). However, further controversy existed regarding specific details of TMSA. Endsley's theory emphasizes perception and comprehension of the environment amid projection into the future; however, it did not contain enough granularity or accuracy in the area of human perception (Elliott et. al., 2009; Gorman et al., 2006; Jodlowski, 2008; Stanton et al., 2001; Wickens, 2008). The TMSA did not emphasize reflective relationships between mental models and knowledge of the present system.

Endsley's view of situation awareness the TMSA is often utilized as the basis for research in areas such as system displays and military operations (Sulistyawati, Wickens, & Chui, 2011). Level 3 situation awareness is the utilization of the situation model to project and predict the future state (Sulistyawati, Wickens, & Chui, 2011). What was needed in this research was to specifically investigate neurocognitive characteristics such as visual attention and visual-spatial working memory, and the effects on pilot workload and situation awareness (Sulistyawati, Wickens, & Chui, 2011). There was a lack and need for additional psychological theory that is based on the neurocognitive abilities to perceive the visual display's cues, predicting situation awareness and workload that is Level 1 situation awareness (Sulistyawati, Wickens, & Chui, 2011). Research continued to struggle to find detailed links between the cognitive demands on pilots and situation awareness, the TMSA was and is vital.

The research performed by Jen-li, Ruey-Yun, and Ching-Jung (2013) examined, display design for unmanned aerial vehicle (UAV) monitoring, and its effects on operator situation awareness, performance, and mental workload involving the TMSA. The operator in UAV flights has to rely primarily on vision in this agent-based system, consequently the question remains to be what role does display design and human visual abilities play in the human-robot interface in order to enhance situation awareness (Jones, Connors, & Endsley, 2011), again illustrating the need to expand the TMSA.

The results illustrated that compared to the conventional display, the effects of situation-augmented display on flight completion time and abnormality detection time were robust across different workloads but error rate and perceived mental workload were unaffected by the display type. With the increasing complexity of new automation technology, visual processes to aid the control operator's situation awareness remain a significant challenge for the field. An important point gained from this study is that the Level 1 SA from the TMSA still presented problems for these researchers in that they had difficulty in measuring the effects between operator visual abilities and display usability (Jen-li et al., 2013). More studies were needed to address these unresolved and important issues (Jen-li et al., 2013) expanding and enhancing the TMSA.

The very recent in-press work by Gugerty, investigated and discussed probable component processes, both perceptual and cognitive, that make up the ability for situation awareness during real-time task. The psychological field needs a better understanding of the foundation of theoretical models, so that through empirical evidence a better conception of situation awareness and its component processes can be achieved (Gugerty, in press). Situation awareness involves elements such as the processes of focal vision, including attention as well as ambient vision processes, including attention capture by abrupt peripheral events. Situation awareness is a complex process that requires further assessment (Gugerty, in press).

Gugerty posited that the cognitive process for Level 1 SA could potentially be automatic, and therefore would place almost no demands on cognitive resources; however, this does not explain the cognitive demand of attention and vigilance, followed by prudence and recognition. Gugerty contested that the TMSA three-level view of SA processes were at odds when it comes to maintaining SA versus acquiring SA. Future research needs to narrow or broaden this view (Gugerty, in press).

The work of Gugerty indicated that increasing SA knowledge further, needs to be accomplished, by discovering, measuring, and quantitatively explaining, describing, and linking these particular key perceptual factors (visual abilities), with the goal being to objectively fill the foundational gaps solidly grounding the TMSA. The TMSA is linked to the AAT, MRT, and the SEEV Model. Wickens and McCarley's (2008) Applied Attention Theory (AAT), offered further support for this research in that AAT indicates that visual attention control, scanning, information sampling, visual search, spatial attention and displays play a role in pilot mental workload, which in turn would imply an influence on situation awareness as well, linking it to the TMSA. Additionally, further AAT clearly illustrates that an understanding of visual processing factors operating in dynamic environments related to attention is incomplete, providing further evidence of the necessity of this study (Wickens & McCarley, 2008). Moreover, Multiple Resource Theory (MRT) (Bulkley et. al, 2009; Lei & Roetting, 2011; Pickel & Staller, 2012; Sarter, 2012; Vidulich & Tsang, 2012) and the Salience Effort Expectancy Value (SEEV) model, which is linked to MRT through the visual modality, articulates the theoretical foundations of this study.

One assumption of the TMSA was that visual and cognitive factors influence situation awareness (Endsley, 1995a, 2012; Vidulich & Tsang, 2012). Previous research had indicated that complex tasks or difficulties in operation (visual factors and task difficulty) results in decreased situation awareness (FAA, 2011; Flight Safety Foundation, 2009; Kang, 2008; Kang, Yuan, Liu, & Liu, 2008; NTSB, 2009; Wickens, 2008). In this study, the visual factors were called "visual abilities" and were a function of the different individuals in the naturally occurring sample. In addition, another cognitive factor was called "task difficulty," was manipulated by the location of the display. According to the TMSA, it could be postulated that increased visual stress and or an increase in mental workload will decrease the level of situation awareness, however, the effects of visual ability on the degree of situation awareness needed to be discovered.

Existing theoretical models explain many aspects of situation awareness; however, the development of situation awareness out of basic perceptual abilities was largely unexplored. This quantitative research examined basic neurocognitive factors including visual skills and working memory in order to identify their specific contributions to the formation of cognitive situation awareness, to in turn address this gap in situation awareness (SA) theory that must be linked before progress could be made. Aircraft piloting was used as a task where situation awareness is critical; trained USAF pilots represent a relatively homogenous, already expert population that reduced the nuisance variance. This study assessed the predictive value of visual attentiveness (V_a), perceptiveness (V_p), and spatial working memory (V_{swm}) as predictors of situation awareness in flight under varying task difficulty using repeated-measures comparisons.

At the completion of this field experiment the data was analyzed, and the tests were statistically significant for the three predictor visual abilities V_p, V_a, and V_{swm} as task difficulty was varied. In addition, multiple regression analyses revealed that the visual abilities together predicted a majority of the variance in situation awareness. Moreover, the Pearson correlation results indicated that V_p had the strongest relationship of the three neurocognitive factors for the overall flight. This reveals that possessing the ability to have a perceptivity, to be insightful, and to have discernment - to perceive that which is ambiguous, is most important. This appears indicative of a fused explicit and implicit process. Interestingly during high task difficulty V_a had the strongest correlation with SA, while during low task difficulty V_{swm} had the highest correlation; this suggests that under high demand possessing the ability to concentrate and be devoted, to be detailed, and responsive becomes the largest determinant. While under low task demand responsiveness and insightfulness is less essential exposing the ability to have working memory, that is responsible for the spatial orientation of one self and the environment, allowing it to become the largest determinant of SA. There are two parts to working memory (WM) one that is performing passive short-term maintenance of what is going on in a somewhat static environment, just using the visuospatial sketchpad and phonological loop, the other part additionally involves active manipulation, such as the transformation of mental representations in a dynamic environment that requires central executive involvement (Kawasaki, Kitajo, & Yamaguchi, 2010).

Prior research was incomplete with regards to the exact role of visual processing abilities; this dissertation research refined measurement of these abilities. The objective measures of situation awareness and workload, in actual flight, did provide the basis for this deeper understanding of situation awareness, as did, testing for participants levels of visual abilities beforehand. Given these findings, the most important predictive measures for future studies would be dynamic visual attention and spatial tests. For the past decade, researchers have been attempting to unravel these important mysteries. This work results in a significant addition and expansion of the existing theoretical model of situation awareness. Through inquiry and discovery this dissertation identified critical variables underlying the formation of situation awareness as well as the relationships among these variables filling this scientific void in theory, grounding the TMSA in concrete and quantifiable perception and cognitive processes. There are practical implications as well, as this study highlights the potential for improved cockpit design and enhancing training by targeting attentional, perceptual, and visuospatial working memory skill learning.

Jones and Endsley (1996) found that the vast majority (77%) of human errors in aviation pointing to situation awareness are caused by difficulties with the perception of needed information, which is the formation of Level 1 situation awareness (Figure 15). In the flying environs, pilots must make time critical decisions; therefore efficient information processing becomes paramount and the ID should be designed so that the pilot can easily perceive the PFI in order to aviate safely.

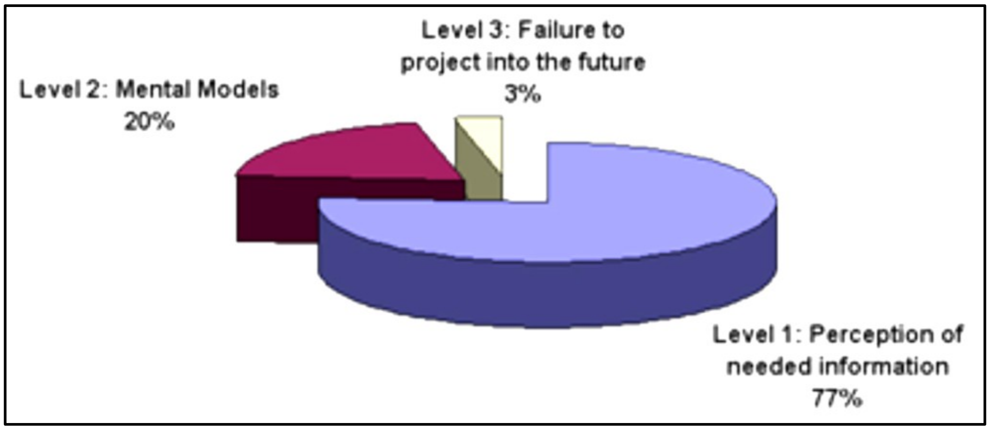

Figure 15. Errors in aviation attributable to situation awareness (Jones & Endsley, 1996). A significant majority of errors are associated with perception, which for aviation is primarily visual.

A reduction in attention due to distractions or increased effort, which can result in increased workload, has been found to undercut situation awareness especially in flying tasks and poses one of the most significant challenges to maintaining situation awareness (Endsley, 2012). Evidence has been found that individuals with better situation awareness seem to achieve higher scores in *working memory, visual processing, temporal processing,* and a *time-sharing ability* (Endsley, 2012; Gugerty & Tirre, 1997). This study certainly supports this premise.

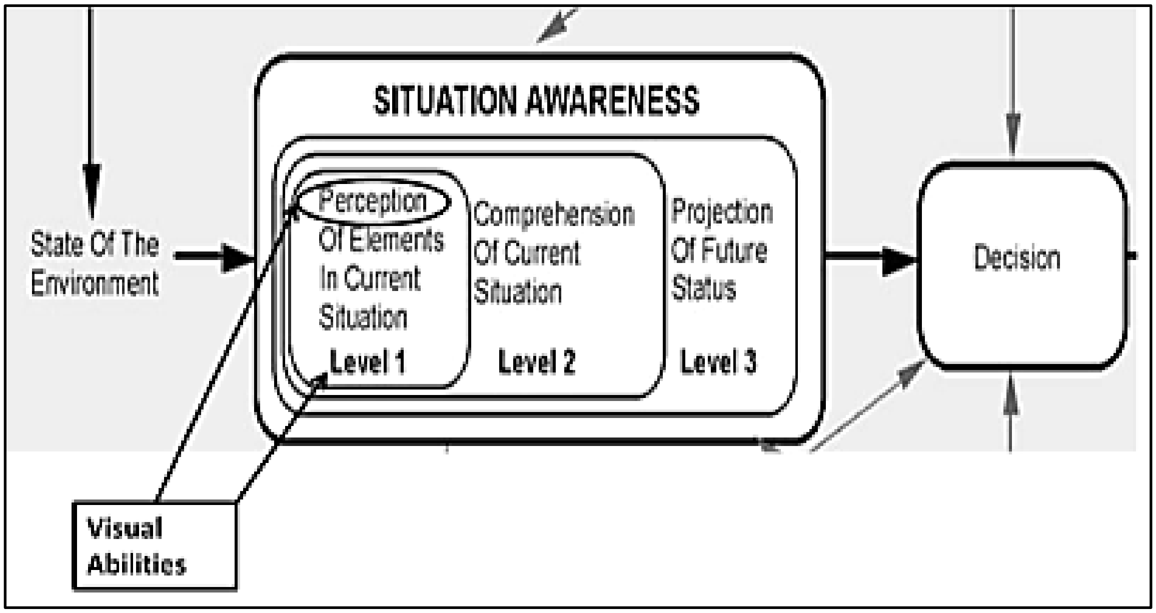

Figure 16. Level-1 SA expanded in Theoretical Model of situation awareness (adapted from Endsley, 1995b). This level of situation awareness is depicted with respect to individual capabilities. The study addressed the potential theoretical links between visual abilities, and situation awareness.

This study was successful in quenching the discontinuity in the TMSA and provides an *Enhanced-TMSA* by discovering the specific measurable neurocognitive attributes (V_a, V_p, V_{swm}) that are the visual abilities that are required to feed Level 1 SA – perception, in order for human SA to be predictable (see Figure 16).

Recommendations

The findings of this study may be advantageous to psychological researchers by providing further insight and understanding of neurocognitive processes that are predictors of situation awareness. In addition, avionics engineers, cognitive engineers, crew system engineers, electronic engineers, and aviation psychologists and human factors specialist may consider the findings necessary for pilot vehicle integration and systems engineering processes in aircraft and UAV design and development, along with discovering new ways in reducing aircraft accidents. The results of the study may also be a base for future investigations of neurocognitive predictors in other populations. It is recommended from this study that further research be extended to other DoD and FAA aviation populations.

Replication of the results would be beneficial in validating the IVA plus and N-back as a practical tool to provide measurements that would be predictive of situation awareness for all types of pilots, automobile drivers, cyber warfare personnel, surgical staff, and the like. Additionally, a replication of the study would be useful to other researchers to validate and determine the reliability of the IVA plus and N-back to corroborate the statistical findings. Additionally, Computerized Cognitive Training (CCT) could be studied to see if it improves an individual's visual abilities.

Further research should also be accomplished with respect to (V_a, V_p, V_{swm}), Qualia, "Consciousness Awareness" versus "Situation Awareness" archetypes, and Dual Processing Theory, in pursuit of a Theoretical Model of Consciousness Awareness (TMCA). As part of the construction of the TMCA, there is a need for a Theory for the Type 2 processes in DPT that culminate in consciousness, as well as differences in Awareness Type 1 versus Awareness Type 2 (Rogers, 2014; R.G. Eggleston, personal communication, Nov 14, 2014). Furthermore, in working towards a Theory of Consciousness Awareness the unexpected query (UQ) as well as expected query (EQ) based on environmental stimuli will need to be research based on environmental stimuli (Rogers, 2014).

Conclusions

In this chapter, the limitations, ethical dimensions, implications, and recommendations of the study were presented. The limitations of the study included the near-random sample and quasi-experimental quantitative method. Ethical aspects included the confidentiality of the participants, and meeting the requirements stipulated in the Family Educational Rights and Privacy Act (Family Educational Rights, 2010) and HIPAA (Creswell, 2009). This study did solve the problem.

This research, due to the scientific exigency, discovered the precise and predictive nexuses for current theories of situation awareness and concrete quantifiable cognitive and perceptual processes. Previous models of situation awareness were still conceptual models that provided little specificity with regards to the neurocognitive processes that are necessary for the formation and maintenance of situation awareness. While the TMSA recognizes perception as a critical first step, there were no specific or quantitative links between perceptual abilities and situation awareness; nor did subsequent work prior to this dissertation been able to clarify the issue, e.g. the effects of visual ability on the level of situation awareness. Needed theoretical advancement in this area was hampered by a lack of specific, testable predictions regarding plausible component processes; there was little theoretical progress due to this.

The three research questions and hypotheses were tested, and the predictors assessed were found to be statistically significant. As a result, all of the alternative hypotheses that indicated significant differences were accepted, and all of the null hypotheses were rejected. Visual attentiveness, visual perceptiveness, and visuospatial working memory were and are predictors of SA. To encapsulate, at the completion of this field experiment, the data were analyzed and the tests were statistically significant for the three-predictor visual abilities V_p, V_a, and V_{swm} as task difficulty was varied.

While filling in a gap in the TMSA specifically at Level 1, this study provides *Theory as Law* to the existing *Theory as Narrative* TMSA. This dissertation was successful in filling the crucial gap in the TMSA and offers an *Enhanced-TMSA* by providing the specific measurable neurocognitive attributes (V_a, V_p, V_{swm}) that are the visual abilities that are required to feed Level 1 SA – perception, allowing SA to be predictable (see Figure 17).

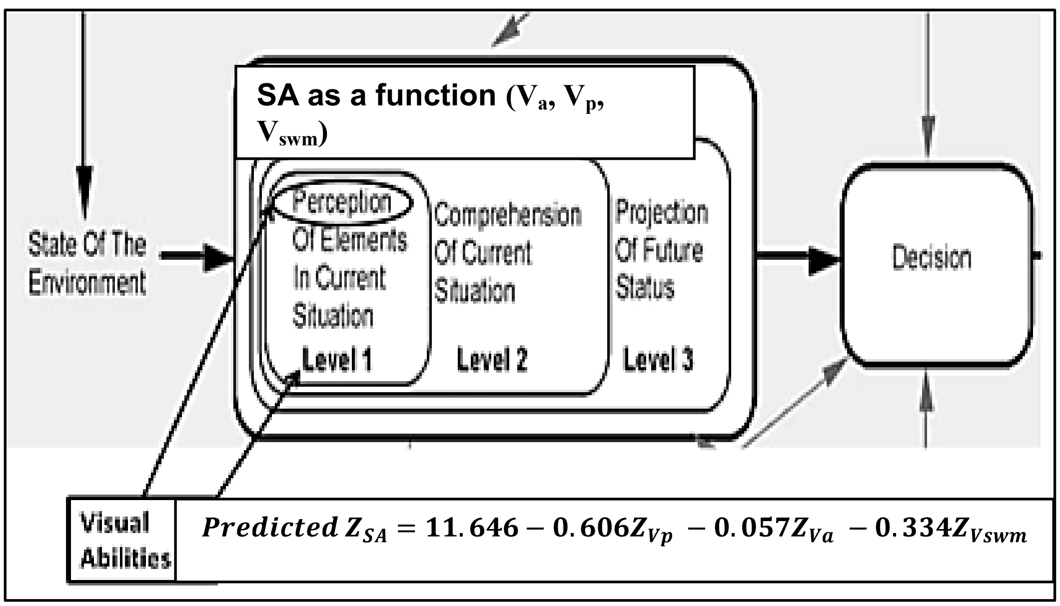

Figure 17. Adding Theory as Law to the existing Theory as Narrative TMSA, by successfully filling a gap in the TMSA offering an Enhanced-TMSA.

In conclusion, this dissertation successfully addressed a fundamental problem in existing psychological theory, expanded the understanding of situation awareness, enhanced the Theoretical Model of Situation Awareness (Figure 17), and provided practical recommendations to enhance safety and improve human performance. This affects society worldwide. This study resonated scientific inquiry and discovery. While much remains to be addressed in this area by future work, these results are a significant step towards a complete understanding of this essential aspect of human psychology.

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Appendices

Appendix A.

Appendix B.

Appendix C.

Appendix A: List of Acronyms

AFFSA – Air Force Flight Standards Agency

AFIT – Air Force Institute of Technology

AFLCMC – Air Force Life Cycle Management Center

AFRL – Air Force Research Laboratory

ANG – Air National Guard

AS – Airlift Squadron

AW – Airlift Wing

BIFOV – Binocular Instantaneous Field of View

CC – Commander

CDEP – Cockpit Design Eye Point

CFIT – Controlled Flight Into Terrain

EASA – European Aviation Safety Agency

EEG – Electroencephalography

ECG – Electrocardiogram

EP – Exit pupil

ER – Eye relief

FAA – Federal Aviation Administration

FERPA – Family Education Rights to Privacy Act

FOV – Field of View

FSF – Flight Safety Foundation

HDD – Head down display

HIPAA – Health Insurance Portability and Accountability Act

HUD – Head up display

HMD – Helmet mounted display

HEMB – HUD Eye Motion Box

ID – Information Display

IVA+ – Integrated Visual and Audio Performance Test Plus

LOS – Line-of-Sight

NTSB – National Transportation Safety Administration

N-Back Test – Number Back (Spatial Working Memory Test by set number "N")

WL – Workload *(Cognitive / Mental)*

P – Pilot

PFI – Primary Flight Information

PRP – Psychological Refractory Period

RT – Reaction Time

SA – Situation Awareness

SWM – Speed-working memory

USAF – United States Air Force

VA – Visual Attention

V_a – Visual Attentiveness

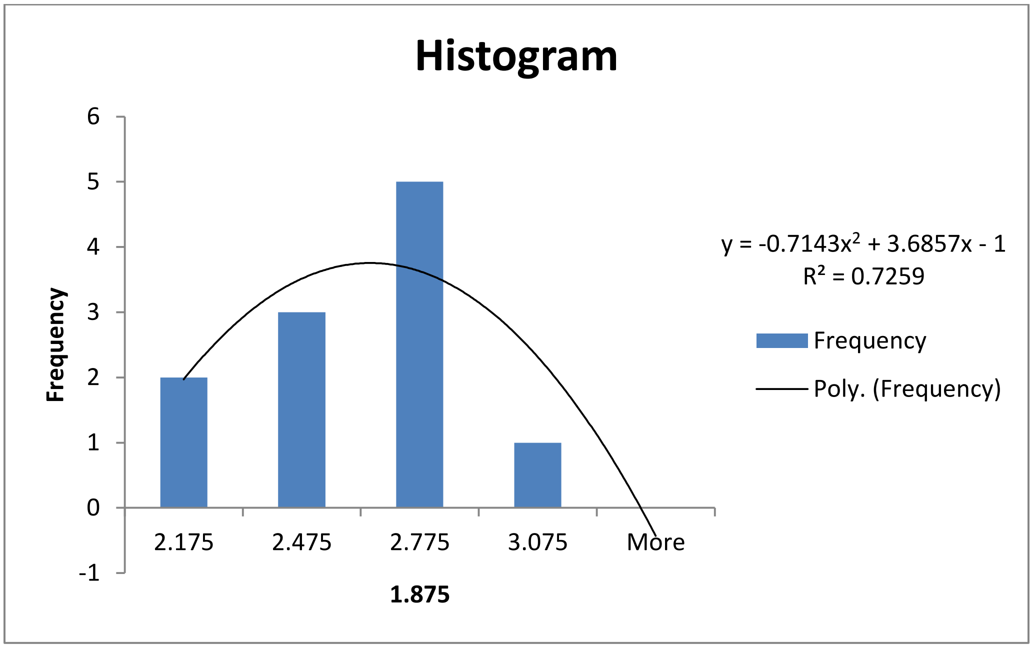
V_p – Visual Perceptiveness

V_{swm} – Visual or Visio- Spatial Working Memory

WM – Working Memory

Appendix B: Instruments, Procedures, Selected Data / Results, and Cert. Letters

Photograph C-27J at Mansfield ANG, Ohio. Approval obtained from 179th AW.



SA Histogram

Coefficient Correlations[a]

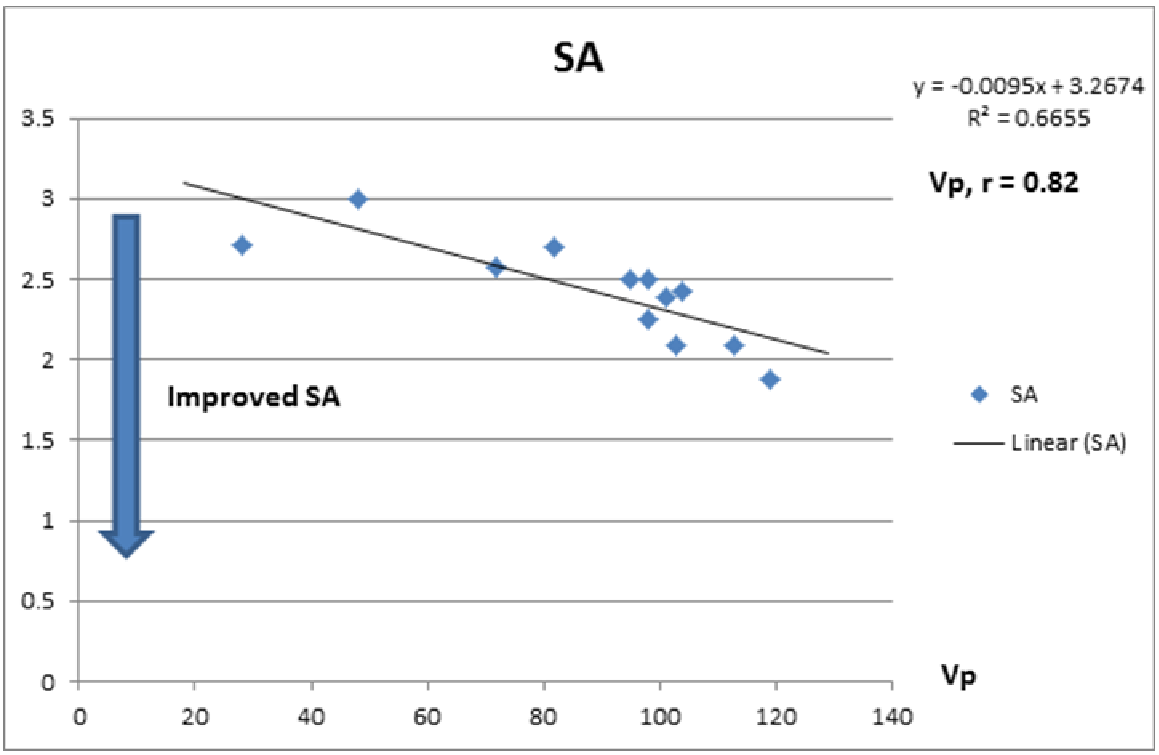
Model			Vswm	Va	Vp
1	Correlations	Vswm	1.000	-.314	-.503
		Va	-.314	1.000	-.113
		Vp	-.503	-.113	1.000
	Covariances	Vswm	2.129E-5	-3.834E-6	-5.853E-6
		Va	-3.834E-6	6.983E-6	-7.552E-7
		Vp	-5.853E-6	-7.552E-7	6.354E-6

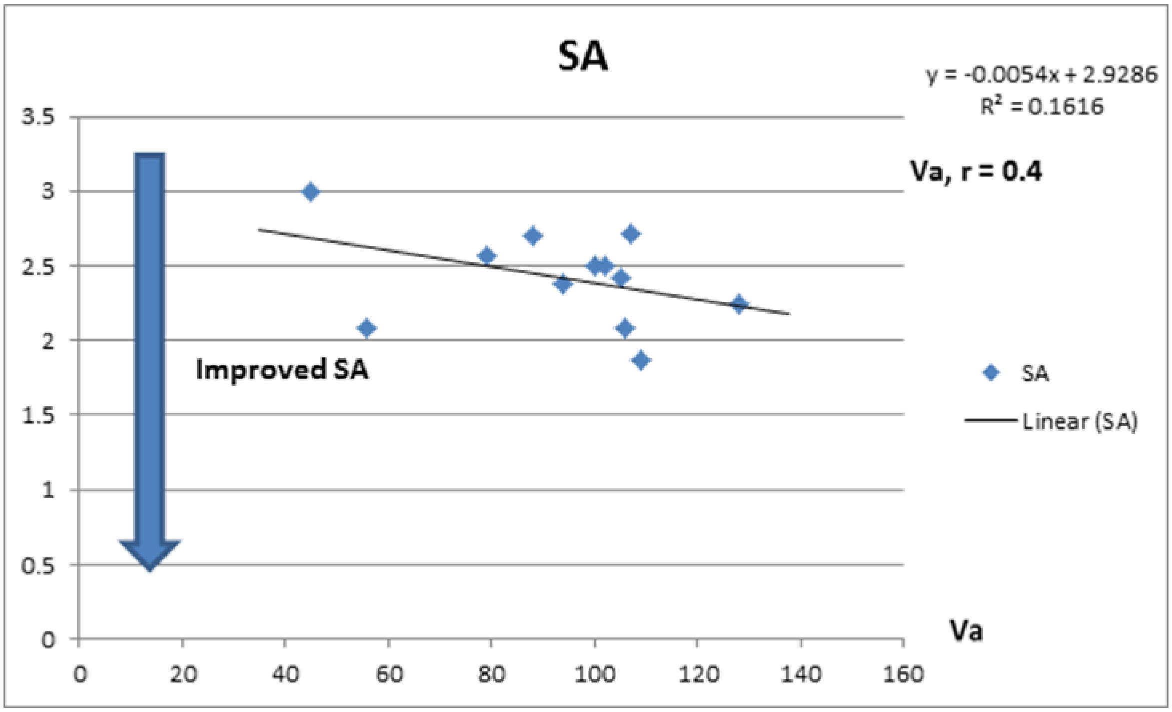
a. Dependent Variable: SA

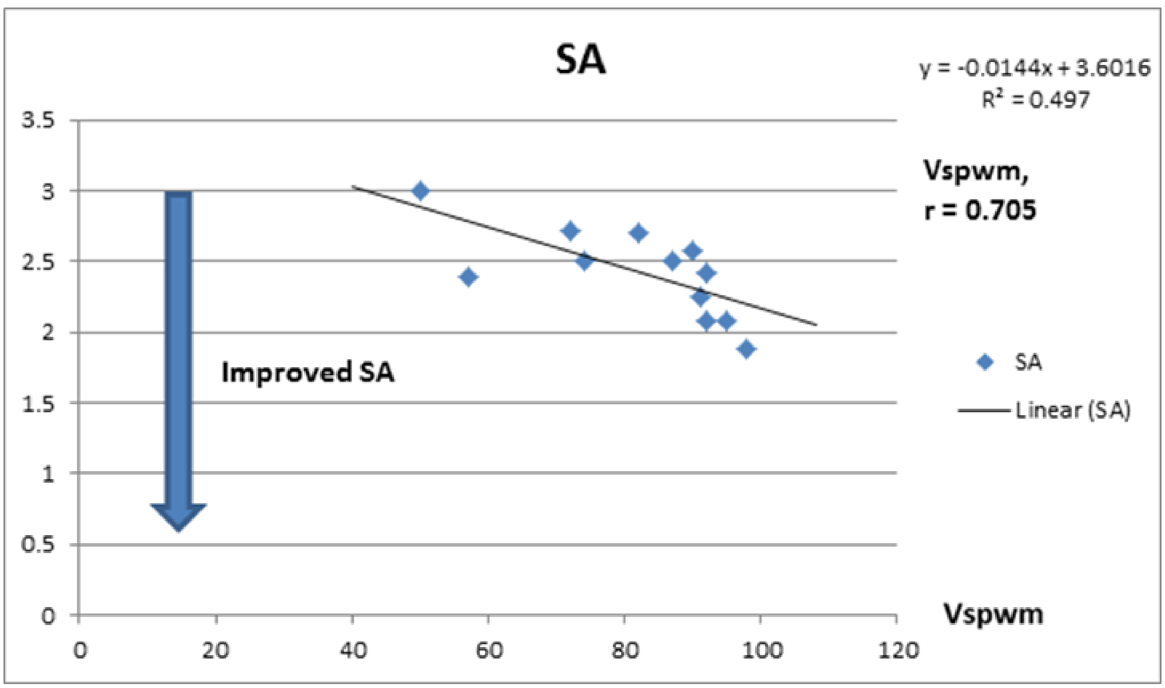
Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Constant)	Vp	Va	Vswm
1	1	3.910	1.000	.00	.00	.00	.00
	2	.048	9.050	.05	.72	.23	.00
	3	.029	11.639	.37	.07	.76	.05
	4	.014	17.009	.57	.20	.01	.95

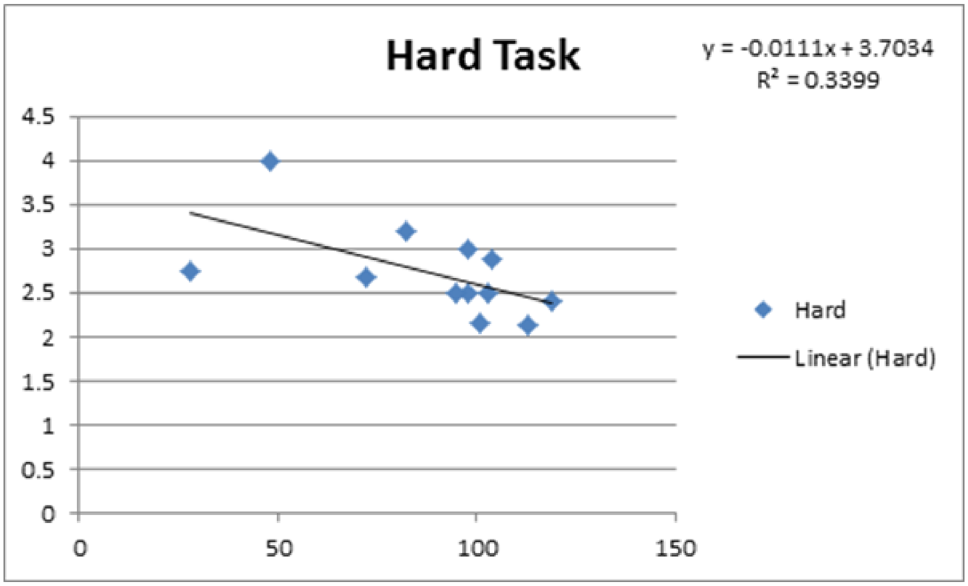
a. Dependent Variable: SA



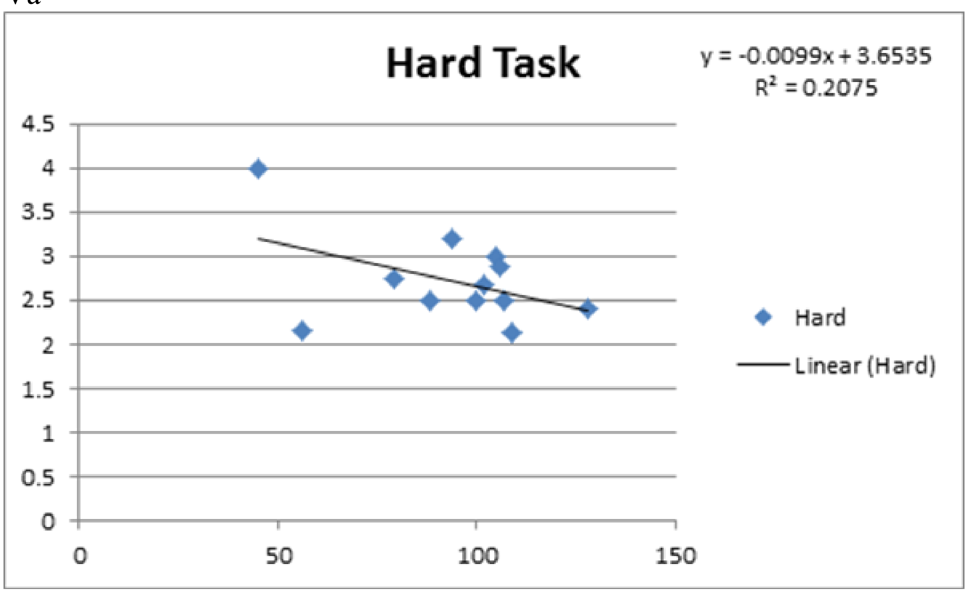

SA
y = -0.0054x + 2.9286
R² = 0.1616
Va, r = 0.4
Improved SA
SA
Linear (SA)
Va
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
160


SA
y = -0.0144x + 3.6016
R² = 0.497
Vspwm,
r = 0.705
Improved SA
SA
Linear (SA)
Vspwm
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120

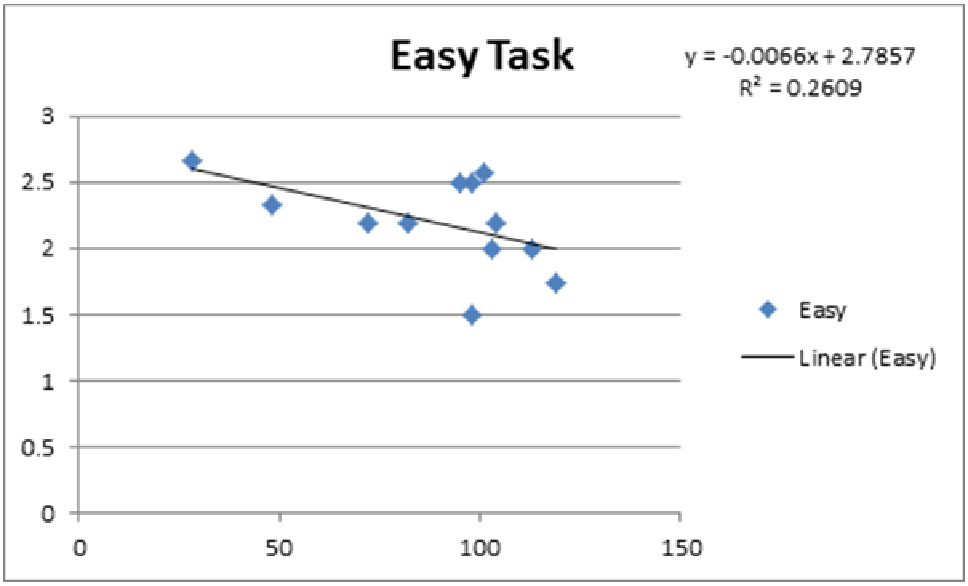
Vp


Hard Task
y = -0.0111x + 3.7034
R² = 0.3399
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
Hard
Linear (Hard)

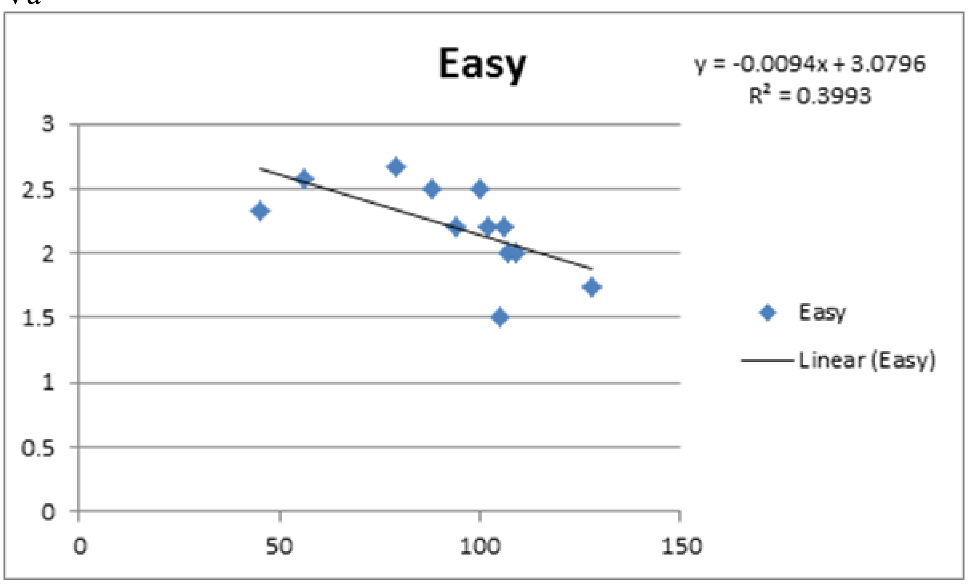
Va


Hard Task
y = -0.0099x + 3.6535
R² = 0.2075
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
Hard
Linear (Hard)

Vp



Va



Descriptive Statistics

	Mean	Std. Deviation	N
SA	2.4238	.31492	12
Vp	88.4167	26.92568	12
Va	93.2500	23.38269	12
Vswm	81.6667	15.39382	12

Coefficient Correlations[a]

Model			Vswm	Va	Vp
1	Correlations	Vswm	1.000	-.314	-.503
		Va	-.314	1.000	-.113
		Vp	-.503	-.113	1.000
	Covariances	Vswm	2.129E-5	-3.834E-6	-5.853E-6
		Va	-3.834E-6	6.983E-6	-7.552E-7
		Vp	-5.853E-6	-7.552E-7	6.354E-6

a. Dependent Variable: SA

Collinearity Diagnostics[a]

				Variance Proportions			
Model	Dimension	Eigenvalue	Condition Index	(Constant)	Vp	Va	Vswm
1	1	3.910	1.000	.00	.00	.00	.00
	2	.048	9.050	.05	.72	.23	.00
	3	.029	11.639	.37	.07	.76	.05
	4	.014	17.009	.57	.20	.01	.95

a. Dependent Variable: SA

Statistics

		Vp	Va	Vswm	**SA**
N	Valid	12	12	12	**12**
	Missing	0	0	0	**0**
Mean		88.4167	93.2500	81.6667	**2.4238**
Std. Error of Mean		7.77278	6.75000	4.44381	**.09091**
Median		98.0000	101.0000	88.5000	**2.4616**
Mode		98.00	45.00[a]	92.00	**2.08**[a]
Std. Deviation		26.92568	23.38269	15.39382	**.31492**
Variance		724.992	546.750	236.970	**.099**
Skewness		-1.324	-.972	-1.126	**-.029**
Std. Error of Skewness		.637	.637	.637	**.637**
Kurtosis		1.199	.709	.251	**-.153**
Std. Error of Kurtosis		1.232	1.232	1.232	**1.232**
Range		91.00	83.00	48.00	**1.13**
Minimum		28.00	45.00	50.00	**1.88**
Maximum		119.00	128.00	98.00	**3.00**
Sum		1061.00	1119.00	980.00	**29.09**
Percentiles	10	34.0000	48.3000	52.1000	**1.9375**
	20	62.4000	69.8000	66.0000	**2.0833**
	25	74.5000	81.2500	72.5000	**2.1250**
	30	81.0000	87.1000	73.8000	**2.2333**
	40	95.6000	95.2000	83.0000	**2.3923**
	50	98.0000	101.0000	88.5000	**2.4616**
	60	100.4000	104.4000	90.8000	**2.5000**
	70	103.1000	106.1000	92.0000	**2.5843**
	75	103.7500	106.7500	92.0000	**2.6679**
	80	107.6000	107.8000	93.2000	**2.7057**
	90	117.2000	122.3000	97.1000	**2.9143**

a. Multiple modes exist. The smallest value is shown

Vp

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	28.00	1	8.3	8.3	8.3
	48.00	1	8.3	8.3	16.7
	72.00	1	8.3	8.3	25.0
	82.00	1	8.3	8.3	33.3
	95.00	1	8.3	8.3	41.7
	98.00	2	16.7	16.7	58.3
	101.00	1	8.3	8.3	66.7
	103.00	1	8.3	8.3	75.0
	104.00	1	8.3	8.3	83.3
	113.00	1	8.3	8.3	91.7
	119.00	1	8.3	8.3	100.0
	Total	12	100.0	100.0	

Va

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	45.00	1	8.3	8.3	8.3
	56.00	1	8.3	8.3	16.7
	79.00	1	8.3	8.3	25.0
	88.00	1	8.3	8.3	33.3
	94.00	1	8.3	8.3	41.7
	100.00	1	8.3	8.3	50.0
	102.00	1	8.3	8.3	58.3
	105.00	1	8.3	8.3	66.7
	106.00	1	8.3	8.3	75.0
	107.00	1	8.3	8.3	83.3
	109.00	1	8.3	8.3	91.7
	128.00	1	8.3	8.3	100.0
	Total	12	100.0	100.0	

Vswm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	50.00	1	8.3	8.3	8.3
	57.00	1	8.3	8.3	16.7
	72.00	1	8.3	8.3	25.0
	74.00	1	8.3	8.3	33.3
	82.00	1	8.3	8.3	41.7
	87.00	1	8.3	8.3	50.0
	90.00	1	8.3	8.3	58.3
	91.00	1	8.3	8.3	66.7
	92.00	2	16.7	16.7	83.3
	95.00	1	8.3	8.3	91.7
	98.00	1	8.3	8.3	100.0
	Total	12	100.0	100.0	

SA

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.88	1	8.3	8.3	8.3
	2.08	2	16.7	16.7	25.0
	2.25	1	8.3	8.3	33.3
	2.38	1	8.3	8.3	41.7
	2.42	1	8.3	8.3	50.0
	2.50	2	16.7	16.7	66.7
	2.57	1	8.3	8.3	75.0
	2.70	1	8.3	8.3	83.3
	2.71	1	8.3	8.3	91.7
	3.00	1	8.3	8.3	100.0
	Total	12	100.0	100.0	

Attachment G: Certification of Vitaport Interference Testing

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS CENTER (AFMC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

21 JUL 1997

MEMORANDUM FOR: AL/CHFP
ATTN: MR. GLENN WILSON

FROM: ASC/ENAE

SUBJECT: Air Force Instruction (AFI) 11-206 Electromagnetic Interference Certification of the Vitaport 2 Physiological Recorder

1. The Vitaport 2 Physiological Recorder has been tested for emissions to the limits of MIL-STD-461D and in accordance with MIL-STD-462D test methods. Equipment certification per AFI 11-206 is as follows:

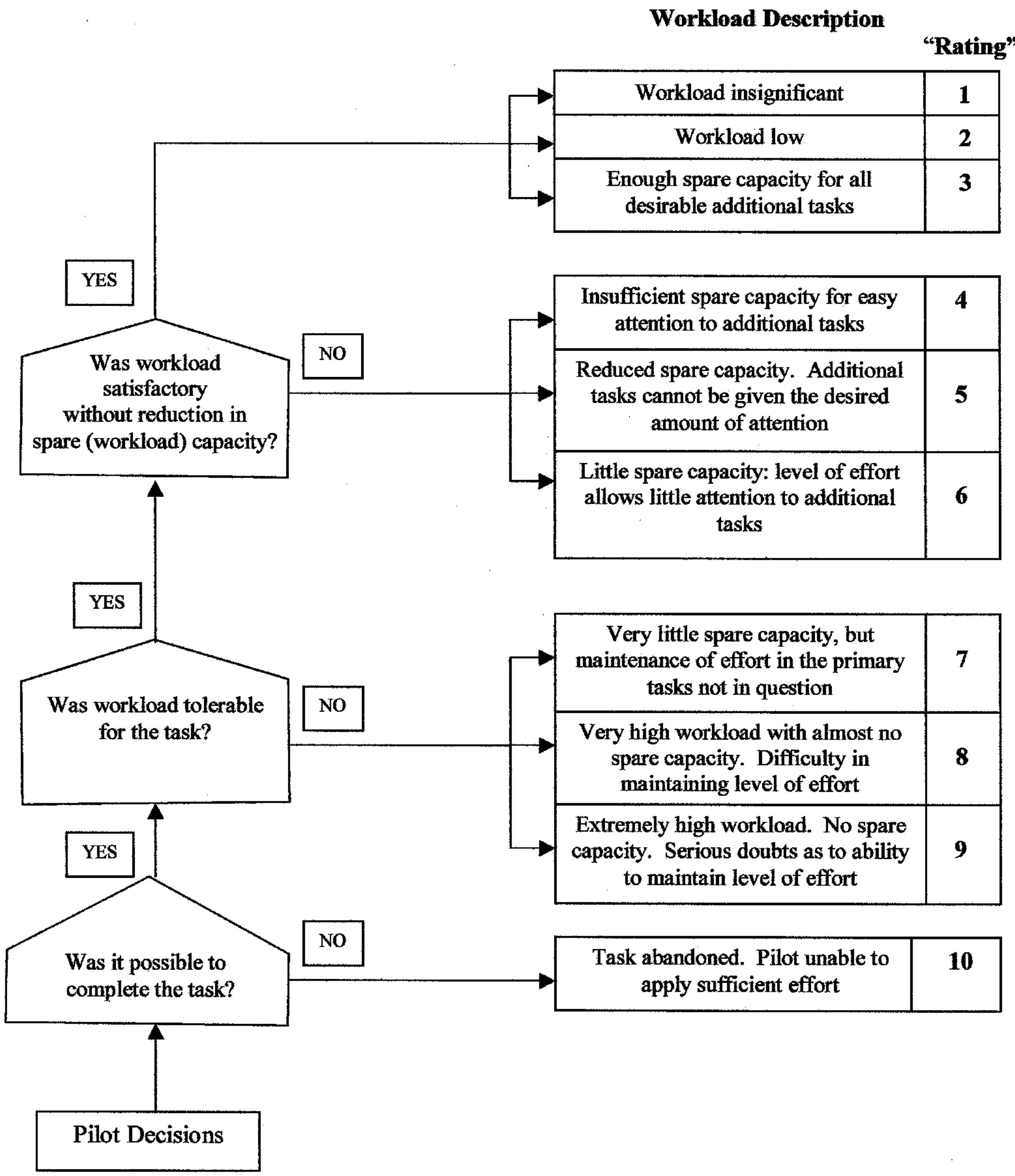
The Vitaport 2 Physiological Recorder has failed to meet required limits for radiated emissions. The Vitaport 2 Physiological Recorder shall not be used during takeoff and landing (below 10,000 ft.), or whenever directed by a crew member. This equipment may be used at other times (above 10,000 ft.), provided the pilot and crew are aware that the equipment is being operated. If interference from the Vitaport 2 Physiological Recorder is suspected, the crew may prohibit its operation.

2. The Vitaport 2 Physiological Recorder can be modified to be used during takeoff and landing (below 10,000 ft.) by installing a double wrapped Steward P/N 28A2024-0A0 Ferrite located 7 cm from the unit on the interconnecting cable. If the modification is incorporated the equipment may be used during all phases of flight with the same restriction that the pilot and crew are aware that the equipment is being operated. If interference from the Vitaport 2 Physiological Recorder is suspected, the crew may prohibit its operation.

3. This certification does not consider the effects that other electronic equipment may have on the Vitaport 2 Physiological Recorder. Radiated and conducted emission testing is performed on your equipment solely to provide reasonable assurance that the equipment will not cause electromagnetic interference problems with existing aircraft equipment. No testing was performed to assess whether the Vitaport 2 Physiological Recorder may be adversely affected by existing aircraft equipment. Testing of your equipment was limited to emissions. Since we did not evaluate your equipment for susceptibility, the potential for degradation of your equipment due to operation of other aircraft systems is unknown.

Intentional Blank

Attachment: Bedford Workload Scale



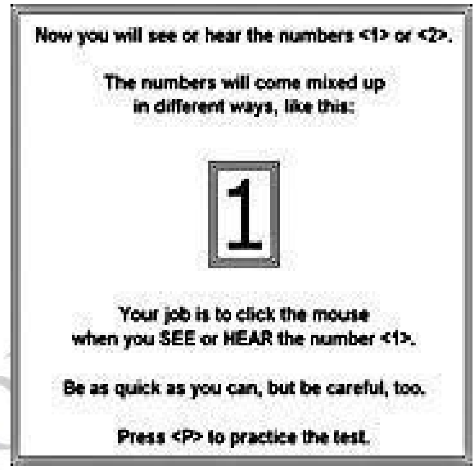
Attachment : China Lake Situation Awareness Scale

Instructions: circle the number that best matches your situational awareness.

Situation Awareness Scale Value	Content
Very Good – 1	• Full knowledge of A/C energy state / tactical environment / mission • Full ability to anticipate / accommodate trends
Good – 2	• Full knowledge of A/C energy state / tactical environment / mission • Partial ability to anticipate / accommodate trends
Adequate – 3	• Full knowledge of A/C energy state / tactical environment / mission • Saturated ability to anticipate / accommodate trends • Some shedding of minor tasks
Poor – 4	• Fair knowledge of A/C energy state / tactical environment / mission • Saturated ability to anticipate / accommodate trends • Shedding of all minor tasks as well as many not essential to flight safety / mission effectiveness
Very Poor – 5	• Minimal knowledge of A/C energy state / tactical environment / mission • Oversaturated ability to anticipate / accommodate trends • Shedding of all tasks not absolutely essential to flight safety / mission effectiveness

Note: A/C – aircraft

Attachment: IVA+ information



IVA+Plus (formerly known as the **IVA**) is a unique combined auditory and visual continuous performance test of attentional functioning, originally developed as a diagnostic aid.

The **IVA+Plus** main test task, which lasts approximately thirteen minutes, presents 500 trials of "1"s and "2"s in a pseudo-random pattern requiring the shifting of sets between the visual and auditory modalities. The subject is required to click the mouse only when he sees or hears a "1" and to inhibit clicking when he sees or hears a "2." During some segments of the **IVA+Plus** test, the "1"s are more common than the "2"s, creating a response set which "pulls" for errors of commission, or impulsivity. During alternate segments of the **IVA+Plus** test, the "1"s occur rarely; this invites more errors of omission, or inattention, since the subject must remain vigilant while he waits for a "1" to occur.

IVA+Plus' normative group (N=1700) is divided by gender, and grouped by age as follows: 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17-18, 19-21, 22-24, 25-29, 30-34, 35-39, 40-44, 45-54, 55-65, 66-96. The database was primarily collected in Richmond, Texas, Michigan, California and Florida. All individuals were excluded who were in therapy, had a history of LD, hyperactivity or attention problems, who were on any type of medication (other than birth control unless >55 years of age), who had a history of neurological problems (dementia, stroke or TBI) and those who could not validly complete the test. A relatively equal number of males and females were included in each age/sex group and an effort was made to have about 30 males and 30 females in each age group though this was not always possible. At about 30 in each group, the standard error ranged between 3-4 points on a standard scale for all the **IVA+Plus** scales. Many different ethnic groups were included in the normative sample, but this data has not been broken down. The normative data is available in the **IVA+Plus** program sub- directory and can be used in most cases to manually calculate the standard scores, except when the standard deviation is small and the percent raw score reported in the reports has been rounded before being displayed (mainly an issue with young adults who make few errors.)

Scoring of the test includes reaction time and accuracy measures, compounded into scores for each of the test segments.

BRUCE E. KLINE, PSY.D. AND ASSOCIATES
CLINICAL PSYCHOLOGISTS

529 E. Stroop Rd
Kettering, OH 45429

Telephone
(937) 294-6004

June 7, 2011

Dr. James C. Christensen, Research Psychologist
Applied Cognitive Neuroscience Branch
711 HPW/RHCP
Air Force Research Laboratories
Building 33 WPAFB, OH 45433

RE: Steven D. Harbour (Ph D, Psychology Candidate)
Use of the Integrated Visual and Auditory performance Plus (IVA+) Test
Letter of Recommendation

Dear Dr. Christensen:

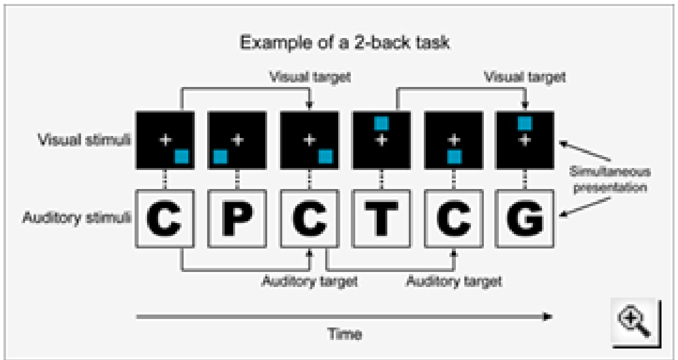
Mr. Steve Harbour has been performing his pre-doctoral internship program, while studying at Northcentral University, in my clinic for the past 2 years. He has logged more than 1000 clinical hours under my supervision. After completing PSY7105 Psychological Test and Measures with the grade of 'A', Steve has scored and interpreted multiple IVA+ tests that he has given to our patients and clients. Mr. Harbour is highly capable, competent, and skilled at running the IVA.

It is with great pleasure that I highly recommend Mr. Harbour as being fully qualified to administer, score, and interpret the results of the Integrated Visual and Auditory performance Plus Test. Steve has my strongest recommendations– as he will perform at the highest level. He came to me as a USAF Test Pilot, Research Human Factors Engineer, and a Ph D in Psychology student. Steve has been performing extensive research in the area of Cognitive Neuroscience and human systems integration (workload and vigilance). His research focuses on Post Traumatic Stress Disorder and Traumatic Brain Injuries and their effects on cognition and memory while investigating and testing new and innovated ways of treatment.

Whether, it is behind the controls of an aircraft as a USAF Test Pilot, or a Human Factors Engineer developing new cockpits for both piloted and unpiloted vehicles, Steve is highly experience performing Human Factors and Psychological research.

Sincerely,

Bruce E. Kline, Psy.D., ABMP, ABFE, AAPM
Clinical Psychologist



Scientists used a modified version of the n-back test, which is schematized above, to achieve gains in fluid intelligence previously thought impossible. The image shows how users were forced to remember both visual and auditory information streams.
Courtesy Martin Buschkuehl

Visuospatial Working Memory (IV). This is working memory that contains visual and spatial information that is stored in the visuospatial sketchpad in the mind (Baddeley, 2006), this immediate memory can be thought of as a workbench where material is continuously being combined and transformed. Visuospatial working memory will be assessed via the spatial n- back task (Gevins & Cutillo, 1993), explained in detail in subsequent section along with validity. This variable's level of measurement is ratio and is a percent of selections that are correct out of the total number; an example could be 85%. Scores can range from 0% correct to 100% correct.

The Visuospatial Working Memory test is a two-back forced choice computerized test paradigm in which the participant is presented with a black X, which can appear at any of five different locations on the screen (AFRL, 2009; Gevins & Cutillo, 1993; Sohn, & Doane, 1997, 2000, 2003). Participants observe a sequence of presentations of the X at the different locations; their task is to compare the current location of the X to where the X appeared two presentations prior. This is done on a continuous basis, requiring the participants to hold the two previous presentation locations in spatial working memory. This test is repeated multiple times, over five minutes. The spatial n-back task is a test of the participant's ability to retain spatial information and to manipulate remembered items in working memory (AFRL, 2009; Sohn, & Doane, 1997, 2000, 2003). It is reliable across people and studies (Owen, McMillan, Laird, & Bullmore, 2005).

OHIO AIR NATIONAL GUARD
HEADQUARTERS 179TH AIRLIFT WING (AMC)
MANSFIELD, OHIO

MEMORANDUM FOR 179AW PERSONNEL

FROM: 179AW/CC

SUBJECT: A letter of support for Research by the Principle Investigators James C. Christensen (AFRL) and Steven D. Harbour (ASC)

Mansfield Air National Guard Base, 179th Airlift Wing will be available for recruitment of participants for the research Titled: C-27J Cockpit and HUD Work Load (WL) and Situation Awareness (SA) Study. The purpose is HUD usability testing and global cockpit workload. The persons conducting the study are: James C. Christensen, Steven D. Harbour, Justin Estepp, 1Lt Tyron Gray, Glenn Wilson, Iris Davis, and Margaret Funke. The proposed study may provide valuable information about C-27J Cockpit and HUD Work Load (WL) and Situation Awareness (SA), HUD usability, global workload, viability of objective and subjective measures, and correlations and causations.

We will allow for recruitment of crewmembers for the research at our unit following IRB approval. The project will only be scheduled for missions that include 1 to 2 participants that have consented to participate in the research per sortie. Pilots will also be asked to perform the IVA test (a simple 13 to 20 minute computer based test) at their convenience with study personnel. Objective measures will occur during specific points in the mission: Low Level, Airdrop, Tactical landings and takeoffs (assaults). As well as Approaches (prec/non-prec) and Touch – n – go's, and take offs and landings. The missions will remain unchanged. After landing and during post flight the crewmember will also be asked to fill-out some surveys.

These objective SA and WL measures could provide more efficient and effective results to the senior leader decision makers while making the C-27J a more effective and safe platform.

Sincerely,

GARY A. MCCUE, Colonel, Ohio ANG
179th Airlift Wing Commander

Appendix C: NCU IRB Approval

Student's name: Steven Harbour
School of Psychology
Dear Steven,
Thank you for your submission of your IRB application and supporting documents to IRB. Please review the feedback provided to you regarding your responses to the IRB application and other supporting documents.
This is an expedited IRB review.

Purpose and Significance section
No comments
Participation Population and Recruitment section
No comments
Research Procedure section
No comments
Risks and Benefits section
No comments
Informed Consent (and Assent) section
No comments
Anonymity or Confidentiality section
No comments
Audio/Video Taping section
No comments
Compensation section
No comments
Deception section
No comments
Debriefing section
No comments
Additional Comments
No comments
Supporting Documents
IRB obtained from USAF
Decision Status: Approve

Good luck with data collection. Be sure to keep in close communication with your mentor and dissertation committee. Keep in mind that if there are any changes to the research procedures, you must notify the IRB.

Sincerely,

Alice Yick, Ph.D.
NCU, Associate Director of IRB and IRB Reviewer
Reference: Steven Harbour

IRB: 2014-08-19-263
Dear Dr. James C Christensen, Dissertation Chair:
Northcentral University approved Steven's research project entitled, *A Neuroergonomic Quasi-Experiment: Predictors of Situation Awareness and Display Usability with USAF Pilots while Performing Complex Tasks.*
As an investigator of human subjects, the student researcher's responsibilities include the following:

1. Report promptly proposed changes in previously approved IRB to your study such as changes to the sampling design, research procedures, consent/assent forms and any other study documents, regardless of how minor the proposed changes might be. (Review the modifications request procedures in the Dissertation Center, under the IRB thread).

2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

3. Report to the IRB the study's closing (i.e., completion of data collection and data analysis). ***Note the above expiration date of the IRB approval.*** It is the researcher's responsibility to report the closing of the study to the IRB before the study's expiration date. (Form is in the Dissertation Center, under the IRB thread).

4. If the study is to continue past the expiration date, student researcher must submit a request for continuing review prior. ***Note the above continuing review due date.*** It is the researcher's responsibility to obtain re-approval from the IRB before the study's expiration date. (Form is in the Dissertation Center, under the IRB thread).

5. If re-approval for continuing review is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately

Sincerely,

Dr. Alice Yick
NCU, Associate Director of IRB and IRB Reviewer
Northcentral University

Appendix D: USAF IRB Approved

A Neuroergonomic Quasi-Experiment: Predictors of Situation Awareness and Display Usability with USAF Pilots while Performing Complex Tasks
USAF IRB Approved
FWRH

1. **Principal Investigator**

Steven Harbour, Human Factors Engineer, NCU Doctoral Candidate ASC/WLNJ, 937-255-8468

Steven.harbour@wpafb.af.mil

2. **Associate Investigator**

a. Dr. James C. Christensen, Ph.D., DR-II, Research Psychologist, NCU Dissertation Chair 711 HPW/RHCP, 937-938-3603
james.christensen@wpafb.af.mil

3. **Medical Consultant or Monitor**

William P. Butler, Col, USAF, MC, CFS; 711 HPW/IR; 937-656-5437;

william.butler3@wpafb.af.mil

4. **Facility/Contractor**

Data collection will take place with the 179th AW, Mansfield, OH. Analysis and storage will take place in B840, WPAFB, OH. Contracting support will be provided by Ball Aerospace under contract number FA8650-08-D-6801. Under the Ball Aerospace DoD Addendum F50343.

5. **Objective**

Despite the scientific exigency there are no precise and predictive nexuses for current theories of situation awareness and specific quantifiable cognitive and perceptual processes. Current models of situation awareness are still conceptual models that provide little specificity with regards to the neurocognitive processes that are necessary for the formation and maintenance of situation awareness. While the Theoretical Model of Situation Awareness (TMSA) recognizes perception as a critical first step, there are no specific or quantitative links between perceptual abilities and situation awareness; nor has subsequent work been able to clarify the issue, e.g. the effects of visual ability on the level of situation awareness. Needed theoretical advancement in this area continues to be hampered by a lack of specific, testable predictions regarding plausible component processes; there has been little theoretical progress due to this. Seminal research found that visual processing was involved in situation awareness. However, the specific component processes have not been explored in detail. Consequently, the primary purpose of this quasi-experimental quantitative study is to test the predictive value of these specific candidate visuo-cognitive abilities Visual Attentiveness, Visual Perceptiveness, and Visuospatial Working Memory as predictors of situation awareness, e.g. the effects of visual ability on the level of situation awareness. Therefore, this project will test the predictive value of these variables as factors between a particular task to be performed and the eventual outcome of situation awareness. As Pavlov, Watson, and Skinner performed field experiments in order to contribute to psychological theory, a field experiment in the paradigm of neuroergonomics will be used for this study. The results of this study will fill in a key gap in the TMSA, and in so doing enable both theoretical refinement and practical applications such as improved procedures, training for pilots, and display design that improve flight safety. Additionally, this research is to evaluate the impact of the C-27J HUD configuration on workload and situation awareness (SA), and to discover human antecedents of SA, while testing the usability of three alternative heads-up displays (HUDs) in the Alenia C-27J. Publicly released information states that the C-27J is still undergoing testing with the first four aircraft having been delivered to the 179^{th} Airlift Wing (Ohio ANG), Mansfield, Ohio; however, at least some of those aircraft are expected to be deployed yet this summer.

6. Background

Based on testing conducted by 179^{th} AW personnel and the C-27J Systems Program Office (SPO), the HUD as currently configured in the aircraft is seriously misaligned with the cockpit design eye point/eye movement box (DEP/EMB). If a pilot correctly positions themselves in the DEP using the design eye spheres on the glare shield, they are approximately 2 inches below the optimal position to view HUD symbology. As a result, the lower portion of the HUD is not visible, with the missing portion ranging from a minimum of 25% of the screen to a maximum of 100%, depending on pilot height and exact position. Raising the seat above the DEP corrects HUD visibility; however when raised sufficiently to view the HUD, the pilot's body obstructs control yoke travel. A significant majority of the available C-27J pilots report at least 30% of aft control authority lost, and at least 30% of bank authority with aft deflection. This loss of yoke travel is a critical issue for tactical airlift missions. Likewise, the loss of some or all HUD symbology is a critical safety issue, particularly in night operations. ASC safety review has consequently designated the HUD/yoke travel hazard category 1A – catastrophic/frequent/high.

Two proposed solutions are being prepared by the Aeronautical Systems Center; the first is to simply disable the HUD, while the second is to use spacers to lower the HUD approximately 2 inches. The following warning is currently provided to pilots: "If the pilot is unable to view all of the HUD symbology without obstructing the ability to aviate the aircraft, then the pilot shall not use the HUD for flight." Lowering the HUD does reduce forward visibility out of the windscreen. In order to make a fully informed decision regarding this issue, ASC has requested that AFRL assist with usability testing on both of these options, as well as the baseline/original HUD. With deployment anticipated this summer, ASC is requesting rapid response from AFRL. In collaboration with the SPO, AFRL is proposing to conduct usability testing in association with training flights conducted by 179 AW pilots.

The testing will consist of standard subjective inventories (Bedford Workload Scale, Roscoe and Ellis, 1990; China Lake Situation Awareness Scale, Adams, Kane, and

Bates, 1998; Attachments b and c), standard cognitive testing (integrated visual/auditory continuous performance test, IVA+ and N-back visio-working memory test; Attachment d), and electrocardiographic (EKG) analysis of heart rate and heart rate variability, and electroencephalogram (EEG) during flight. Subjective scales have been widely used to assess workload; however, the SPO is concerned that limiting data collection to subjective measures may result in skewed or uninformative results due to deployment pressure. As a result, the subjective data will be complemented with objective physiological data that is sensitive to workload differences, specifically heart rate and heart rate variability (Hankins and Wilson, 1998; Nickel and Nachreiner, 2003). The purpose of the IVA+ (Turner and Sandford, 1995) is to also assess attention switching and cognitive performance; one of the primary consequences of disabling or using the original HUD will be increased workload associated with rapid attention switching between the primary flight display (heads-down display, HDD) and the view outside the cockpit. By including one quick test of basic cognitive ability, we will have a covariate that should aid in interpreting the results, e.g. by enabling the binning of data based on attention switching performance.

7. Impact

As a category 1A safety hazard, the C-27Js will not deploy until adequate resolution has been reached. This research will quantify the impact of disabling or lowering the HUD, in terms of subjective workload and situation awareness, and objective workload. The results of this research will enable a go/no go decision.

8. Experimental Plan

a. Equipment:

The Bedford Workload and China Lake SA scales will be delivered via paper questionnaires. The IVA continuous performance test will be delivered via laptop computer provided by AFRL personnel. The electrocardiographic data will be collected using a Vitaport system (Temec Instruments B.V., Kerkrade, Netherlands), which is a small, portable pilot-worn physiological data collection system with onboard digital data storage (e.g. approved protocol FWR20100077H). This device has been certified for use in all flight phases subject to aircrew consent (Attachment G, Section 2; the ferrite core wrapper will be used at all times). Sterile, single-use ECG leads will be placed on the sternum and clavicle and EEG leads will be placed on the scalp in accordance with standard test procedures.

b. Subjects:

a. Source: All participants will be rated C-27J ANG pilots on active flight status at Mansfield, OH. Approximately 25 assigned pilots currently meet those criteria.

b. Number required: Based on the AFRL team's previous experience conducting workload studies, approximately 12 individuals will be required to achieve adequate statistical power.

c. Inclusion/exclusion/age range: To participate, pilots must be rated C-27J pilots, on active flight status, and currently flying training missions. There are no additional requirements or limitations on participation.

c. Duration:
This testing will take no more than approximately 365 days from approval (planned to be completed in 15 to 30 calendar days from start), and is driven by ASC requirements (after NCU IRB approval). Some additional follow up analyses may be conducted.

d. Description of experiment, data collection, and analysis:
This project will piggyback on normal training sorties conducted by the 179 AW; research personnel will not direct, schedule, or otherwise interfere in training missions. While a variety of sorties are being flown, the sorties determined to be of greatest interest based on 179 AW input are the following:

1. Short-field take-off and landing, day
2. Short-field take-off and landing, night
3. Low level air drop, day
4. Low level air drop, night

We will endeavor to obtain one sortie of each type from 12 pilots total. Ideally, this will be crossed with HUD types: no HUD (HDD), and the moved/new HUD, resulting in a total of approximately 8 sorties equivalent per pilot (2 or more pilots per sortie). We understand and expect that this ideal will not be guaranteed achievable with all pilots and mission constraints. Order and time between sorties will not be controlled, to avoid any interference with training activities.

Pilots will be briefed as to the purpose of the study, and then given an invitation memo (Attachment f). Pilots who wish to participate will complete comprehensive written informed consent.

Data collection will commence with preflight delivery of the IVA+ (once per pilot), the 2-Back spatial working memory test, and placement of the ECG leads on sternum and clavicles and EEG leads on scalp (once per day/sortie). Female pilots will be given the opportunity to place their own leads in private following brief researcher instruction.

The Vitaport data acquisition box will be activated after placing the leads, and left on for the duration of the sortie. Preflight data will be used to establish individual baselines for each flight. Timestamps will be taken during each phase of the sortie to enable analyses; the Vitaport will be deactivated during removal of the leads postflight.

During sortie debriefing, each pilot will be asked to complete one Bedford and one China Lake scale, with instructions to consider the HUD or lack thereof or the HDD.

Analysis of subjective, IVA+ performance, N-back, and ECG / EEG data will include within subjects repeated measures analyses of variance (ANOVA), followed by analyses of simple main effects, interactions and multiple comparisons. We are especially concerned with testing for significant differences among the HUD and HDD conditions.

Safety monitoring:
All flight safety issues are the responsibility of the appropriate Safety Review Board and squadron SOF. Researchers will be responsible for monitoring participants for any adverse reactions possibly associated with electrode placement, such as urticarial (hives) or contact dermatitis. In such an event, the medical monitor would be immediately notified.

Confidentiality protection:
In order to avoid the collection of direct or indirect personally identifiable information, there will be no demographic data collected. Each pilot participant will receive a randomly-generated, non-sequential numeric identifier that will be used to identify their data. Individual data will include subjective responses to survey questions, responses to computer-based testing, and electrocardiographic data. Investigators will neither collect nor disclose information that allows linkage of the data to a specific participant. No personal identifiers will be included in the data sets used in this study. All participation is voluntary. In order to avoid any possibility for inadvertently collecting medically relevant information from ECG/EEG, those data will not be read or interpreted by humans in raw form; only machine-generated summaries of heart rate and heart rate variability (standard deviation of heart rate) will be read by AFRL personnel. The AFRL personnel doing this analysis are not medical personnel and are not qualified to interpret any anomalous findings; consequently, no attempt will be made to read raw waveforms.
Paper workload and SA scales will be stored in a locked file cabinet within a room in B33, WPAFB that can only be accessed by AFRL staff; electronic data will be stored in removable media (secure digital, CD, or portable hard drive) in a similar locked file cabinet. When reporting the results of this study, averages and standard deviations for each of the primary measures as well as statistically significant differences among conditions will be presented. These averages would contain at minimum the 12 participants expected. If any individual exemplars are provided to illustrate an event, only short segments of data without coded numeric identifiers will be shown. Original paper scales will never be copied or reproduced; if included in a report only digitally recoded data will be included. This data is intended to be provided to ASC and ANG to support equipment and deployment decisions.

9. Risk Analysis

The risk is **minimal**. All testing will be done using standard tests that are non-invasive. The probability and magnitude of harm or discomfort anticipated in completing the testing is not greater than ordinarily encountered daily life events or during the performance of completing routine physical or psychological questionnaires. To mitigate any potential psychological harm, individual results will never be disclosed. This is also intended to substantiate our protection against adverse effects on a pilot’s flight status.

We are not evaluating individual cockpit performance. The use of disposable, sterile ECG / EEG leads is a standard procedure conducted in an outpatient or field environment hundreds of times each day. All sorties are normal training sorties with minimal risk. 5

10. References

a. Adams, S.R., Kane, R. & Bates R. (1998). Validation of the China Lake Situational Awareness scale with 3D SART and S-CAT. China Lake, CA: Naval Air Warfare Center Weapons Division (452330D).
b. Hankins, T.C. & Wilson, G.F. (1998). A comparison of heart rate, eye activity, EEG, and subjective measures of pilot mental workload during flight. *Aviation, Space and Environmental Medicine*, 69, 360-367.
c. Nickel, P., & Nachreiner, F. (2003). Sensitivity and diagnosticity of the 0.1-Hz component of heart rate variability as an indicator of mental workload. *Human Factors*, 45(4), 575-590.
d. Roscoe, A.H., & Ellis, G.A. (1990). A subjective rating scale for assessing pilot workload in flight: A decade of practical use. Bedford, UK: Royal Aerospace Establishment.
e. Turner, A. & Sandford, J.A. (1995). A normative study of IVA: Integrated Visual and Auditory Continuous Performance Test. *Proceedings of the Annual Meeting of the American Psychological Association*. New York, NY.

11. Attachments

a. Informed Consent Document
b. Bedford Workload Scale
c. China Lake SA Scale
d. Screenshot of IVA+, mfr information, and N-Back
e. Col. McCue's letter of support
f. Invitation letter
g. Certification letter for Vitaport interference testing (EKG/EEG)
h. CITI Certificate

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Attachment: Informed Consent

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Informed Consent
Document For
Usability Testing of the C-27J HUD and predictors of Situation Awareness Research

A Neuroergonomic Quasi-Experiment: Predictors of Situation Awareness and Display Usability with USAF Pilots while Performing Complex Tasks
Usability Testing of C-27J HUD

179 AW, Mansfield, Ohio

711 HPW/RHCP, WPAFB, OH,
Building 33

A Neuroergonomic Quasi-Experiment: Predictors of Situation Awareness and Display Usability with USAF Pilots while Performing Complex Tasks
FWRH

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1. **Nature and purpose:** You have been offered the opportunity to participate in the “Usability Testing of the C-27J HUD” research study and predictors of Situation Awareness. Your participation will occur at the 179 AW, Mansfield, Ohio.

   The purpose of this research is to evaluate the impact of the C-27J HUD configuration on workload and situation awareness (SA), and to discover human antecedents of SA.

The time requirement for each volunteer subject is anticipated to be an additional 30 minutes added to the normal pre and post sortie activities. This project will piggyback on normal training sorties conducted by the 179 AW; research personnel will not direct, schedule, or otherwise interfere in training missions. A total of 8 sorties will be included from each participant. A total of approximately 12 subjects will be enrolled in this study.

2. **Experimental procedures:** If you decide to participate, testing will involve the use of survey questionnaires that ask about workload and situation awareness, a computer-based test of your ability to divide attention, and the collection of heart activity (electrocardiography – ECG) and EEG indicative of stress and workload in flight. To record the electrical activity of your heart, electrodes will be attached to your collar bone and chest, and EEG to your scalp. The data regarding heart activity will not be read by a human, but machine-coded into basic data about heart rate, and standard cognition testing (IVA+ and N-back) will be conducted to be explained by researcher for SA antecedent research. The Bedford WL and China Lake SA surveys will be handed out to be filled in at the end of the sortie. The personnel conducting this study will not examine or interpret this data for any medical anomaly, nor are they qualified to do so. Individual results will not be shared with your unit. Participating in this study will not impact your flight status. Under that protection, we encourage you to be completely honest and provide us with as much feedback as possible. In this way, you are helping us to generate sound, quantitative results to enable the best decision-making possible regarding the configuration of your aircraft's systems and scientific research towards predicting SA.

3. **Discomfort and risks:** The experimental procedures do not present any unusual or risky procedures or equipment. However, discomforts may consist of mild skin irritation where the ECG / EEG electrodes are placed. Potential risks include an allergic reaction that could occur at the site of electrode placement; thus participants with a history of urticaria (hives) not participate in the study.

4. **Precautions for female subjects or subjects who are or may become pregnant during the course of this study:** We will not recruit pregnant women for this research study.

5. **Benefits:** You are not expected to benefit directly from participation in this research study.

6. **Compensation:** If you are active duty, guard, or reserve military you will receive your normal duty pay.

7. **Alternatives:** Your alternative is to choose not to participate in this study.

Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify one of the investigators of this study to discontinue.

8. **Entitlements and confidentiality:**

   a. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations and the Health Insurance Portability and Accountability Act (HIPAA), and its implementing regulations, when applicable, and the Freedom of Information Act, 5

U.S.C. Sec 552, and its implementing regulations when applicable. Your personal information will be stored in a locked cabinet in an office that is locked when not occupied. Electronic files containing your personal information will be password protected and stored only on a secure server. It is intended that the only people having access to your information will be the researchers named above and this study's Medical Monitor or Consultant, the AFRL Wright Site IRB, the Air Force Surgeon General's Research Compliance office, the Director of Defense Research and Engineering office or any other IRB involved in the review and approval of this protocol. When no longer needed for research purposes your information will be destroyed in a secure manner (shredding). Complete confidentiality cannot be promised, in particular for military personnel, whose health or fitness for duty information may be required to be reported to appropriate medical or command authorities. If such information is to be reported, you will be informed of what is being reported and the reason for the report.

   b. Your entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if you desire further information you may contact the base legal office (ASC/JA, 257-6143 for Wright-Patterson AFB). In the event of a research related injury, you may contact the AFRL IRB office at 937-656- 5689 or afrl.heh.dl.irb@wpafb.af.mil.

   c. If an unanticipated event (medical misadventure) occurs during your participation in this study, you will be informed. If you are not competent at the time to understand the nature of the event, such information will be brought to the attention of your next of kin or other listed emergency contact.

The decision to participate in this research is completely voluntary on your part. No one may coerce or intimidate you into participating in this program. You are participating because you want to. Steven D. Harbour, or an associate, has adequately answered any and all questions you have about this study, your participation, and the procedures involved. Steven D. Harbour can be reached at

(937) 255-8748. Steven D. Harbour or an associate will be available to answer any questions concerning procedures throughout this study. If significant new findings develop during the course of this research, which may relate to your decision to continue participation, you will be informed. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify one of the investigators of this study to discontinue. The investigator or medical monitor of this study may terminate your participation in this study if she or he feels this to be in your best interest. If you have any questions or concerns about your participation in this study or your rights as a research subject, please contact Col William P. Butler; 937-656-5437 or william.butler3@wpafb.af.mil.

e. No personally identifiable information will be obtained for this study, unless you consent below to photography and/or videotaping. Such recordings, if made, will not show your face or name tape.

f. Your participation in this study may be photographed, filmed or audio/videotaped. The purpose of these recordings is for training and data collection purposes. Any release of records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 55 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to unauthorized source without your permission. These recording may be used for presentation or publication, with your signed permission. They will be stored in a locked cabinet in a room that is locked when not occupied. Only the investigators of this study will have access to these media. They will be maintained for 5 years.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer Signature____**Date**________________

Volunteer Name (printed)____

Advising Investigator Signature______________________**Date** __________________

Investigator Name (printed)____

Witness Signature_________________________________**Date** __________________

Witness Name (printed)____

We may wish to present some of the video/audio recordings or photographs from this study as part of reporting the outcome to Air Force leadership, and/or in sharing scientific results with the research community in an academic conference setting. If you consent to the use of your image for publication or presentation in such settings, please sign below. Choosing not to sign will not impact your participation in the study.

Volunteer Signature____Date________________

Privacy Act Statement

Authority: We are requesting disclosure of personal information.. Researchers are authorized to collect personal information on research subjects under The Privacy Act-5 USC 552a, 10 USC 55, 10 USC 8013, 32 CFR 219, 45 CFR Part 46, and EO 9397, November 1943.
Purpose: It is possible that latent risks or injuries inherent in this experiment will not be discovered until some time in the future. The purpose of collecting this information is to aid researchers in locating you at a future date if further disclosures are appropriate.
Routine Uses: Information may be furnished to Federal, State and local agencies for any uses published by the Air Force in the Federal Register, 52 FR 16431, to include, furtherance of the research involved with this study and to provide medical care.
Disclosure: Disclosure of the requested information is voluntary. No adverse action whatsoever will be taken against you, and no privilege will be denied you based on the fact you do not disclose this information. However, your participation in this study may be impacted by a refusal to provide this information.

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